Biplane to Monoplane:

Twenty Years of Technological Development in British Fighter Aircraft, 1919-1939

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DECLARATION BY CANDIDATE

I affirm that the present thesis, 'Biplane to Monoplane: Twenty Years of Technological Development in British Fighter Aircraft, 1919-1939', has been composed by me, and that the work is my own. The thesis has not been submitted for any other degree or professional qualification, neither has it been published in whole or in part. I have read and understood The University of Edinburgh guidelines on plagiarism and declare that this thesis is all my own work except where I indicate otherwise by proper use of quotes and references.

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PAUL KELLY

Table of Contents

ILLUSTRATIONS

INTRODUCTION

In the summer of 1940 around five thousand aircraft clashed during several months for control of the skies over Britain. The fighter aircraft used by the German *Luftwaffe* and British *Royal Air Force* were, for the most part, very similar. They were monoplane airframes (fig. 3) made with a metal structure and covered with fabric or metal skin, their engines produced around 1,000 h.p., and the aircraft themselves achieved speeds of around 350 to 370 m.p.h. They had retractable undercarriages and were bristling with armaments.[1] These aircraft stood in stark contrast to those used just over twenty years earlier in the First World War. Those machines (fig. 2) were biplanes,[2] almost exclusively made from wood, covered in a doped fabric, their engines produced around 400 h.p., with speeds at around 120 m.p.h., they had fixed undercarriages, one or two machine guns and were largely un-armoured.

In a little over twenty years the basic form of fighter aircraft had changed, and the materials used in their construction had changed. The engines, guns, interior structure and even the operational roles to which they were assigned had been altered to greater or lesser extents. The period 1918-1939 was, therefore, very important in the development of British fighter aircraft, as it was in aviation technology more generally.[3]

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[1] The Supermarine *Spitfire Mk. I* used in the Battle of Britain was powered by a Rolls-Royce *Merlin Mk. II* 1,030 horse-power aero-engine and achieved a top speed of around 367 m.p.h. The main fighter used by the *Luftwaffe*, the Messerschmitt Bf 109 used a 1,085 h.p. Daimler-Benz *601A* engine and achieved around 342-348 m.p.h.

[2] Monoplanes also existed at this time, as did triplanes and even quadruplanes, but biplanes were overwhelmingly used as the form for combat aircraft of all types.

[3] For example see: C. H. Gibbs-Smith, *Aviation - An Historical Survey*, Second ed. (London: HMSO, 1985). David Edgerton, *England and the Aeroplane - An Essay on a Militant and Technological Nation* (Manchester: Macmillan, 1991). Peter Fearon, "The British Airframe Industry and the State, 1918-1935," *The Economic History Review* 27, no. 2 (1974).

WHAT IS A 'FIGHTER'?

It may be helpful here to set out what a 'fighter' aircraft actually is, delineating some terms used frequently throughout the thesis, not only to have a clear idea in mind of what we are talking about but also, at this early stage, to be made aware of the fact that we are discussing not one technology (the 'aircraft') but hundreds. A fighter aircraft of the first half of the twentieth century (from 1916 when the Royal Flying Corps was first equipped with fighter squadrons)[4] was distinct from other forms of military aircraft such as bombers and reconnaissance, in that its sole mission was attacking other aircraft.[5]

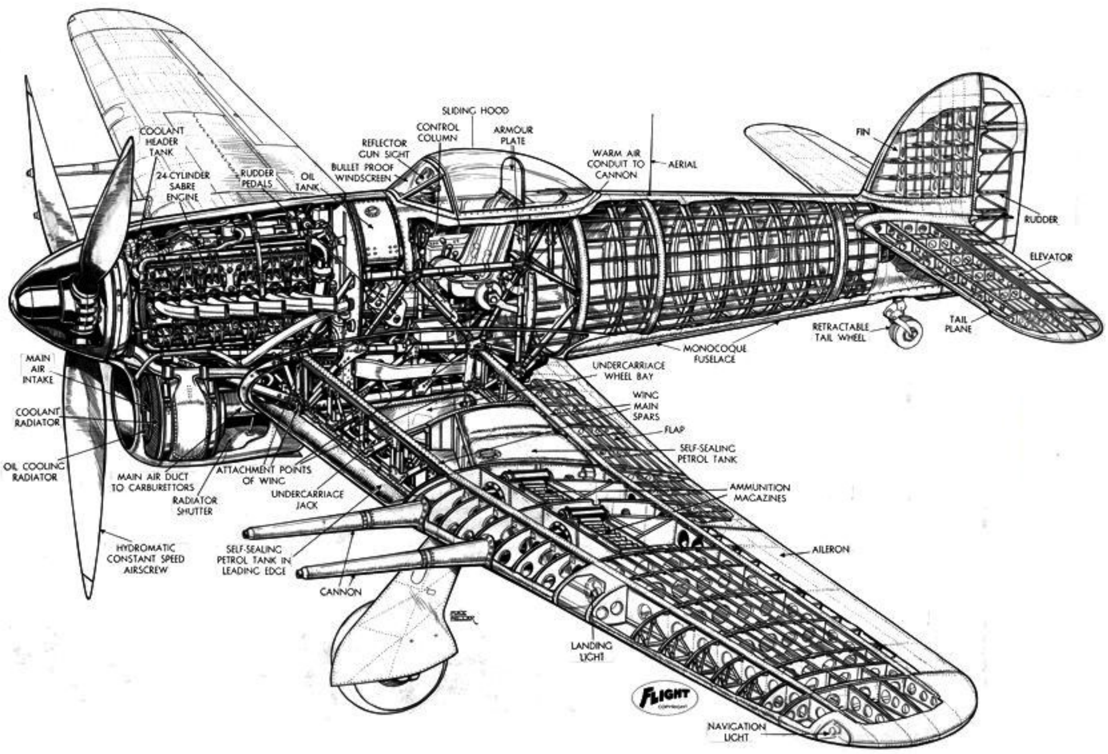

Figure 1 - Hawker Typhoon (1941)[6]

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[4] J. O. Andrews, "The Single Seater Fighter Tactical Unit for Home Defence," *Royal United Service Institution* 77(1932): p. 384.
[5] For instance, a bomber design would prioritise 'useful load' or the amount of munitions and fuel it can carry, reconnaissance aircraft would prioritise speed (they were generally unarmed).
[6] From *Flight* magazine. The *Typhoon* is a World War Two-era fighter/bomber. Although not a part of this thesis, this cutaway is one of the best to illustrate the different parts and layers of a military aircraft of the latter 1930s..

A fighter was therefore supposed to possess the highest speed and rate-of-climb (time to reach a given altitude) possible, superior manoeuvrability, and was designed, in essence, as a gun platform.[7] Its operational roles would be changed and defined throughout the First World War. Indeed, papers written on the best use of fighter aircraft in the 1930s still took the experience gained during the War as their starting point.[8] The War defined two main operational roles for the new fighter aircraft. The first was the interception and destruction of enemy aircraft (fighters, bombers, zeppelins, balloons, and reconnaissance aircraft). The second was the protection of friendly aircraft against the enemy.

Regarding construction, designers wanted the lightest possible airframe for the greatest strength they could achieve. Designing a fighter, as with any other aircraft, was a series of trade-offs searching for the optimum economies of form, weight, fuel and maintenance.[9] In terms of the major component systems of an aircraft, broadly, there is the fuselage, wings, flaps and ailerons, engine, propeller, undercarriage and weapons systems. Figure one illustrates just some of the many smaller components that make up an aircraft of that time.

During the inter-war period the Royal Air Force developed two types of fighter, designed with two different operational roles in mind. Their role in the defence of London and the Air Staff distinction between the two types is an important factor in understanding RAF fighter development during the period.[10] Firstly, the 'interception fighter' operated only during the day to compete with the faster enemy

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[7] Rate-of-climb improved by 40% in fighters between 1918 and 1931. J. O. Andrews, "The Strategic Role of Air Forces," *Royal United Service Institution* 76(1931): p. 742.
[8] Ibid. Andrews, "The Single Seater Fighter Tactical Unit for Home Defence." Saracen, "Air Forces and the Offensive," *Royal United Service Institution* 78(1933).
[9] R. V. Goddard, "The Development of Aircraft and its Influence on Air Operations," *Royal United Service Institution* 79(1934): p. 450.
[10] Colin Sinnott, *The R.A.F. and Aircraft Design, 1923-1939 - Air Staff Operational Requirements* (London: Cass, 2001). p. 18.

day bombers. They were required to be fast and operated from advanced bases near the coast, and had a high performance and volume of fire. However, this concept, to intercept incoming formations and chase outgoing ones, was found to be flawed during the Air Exercises of the late 1920s and early 1930s due to the inability to give squadrons adequate warning of attack and at that point the inadequate performance of the aircraft used.[11]

Secondly, there was the ‘zone fighter’, which was used during both day and night. The defence of Britain using zone aircraft was laid out in three stages: first, the anti-aircraft Gun Zone; then, the Aircraft Fighting Zone; and third, a second Gun Zone (for defence of London). The Aircraft Fighting Zone comprised (in 1923) fourteen ‘Fighting Squadrons’ with “each squadron assigned to a defensive sector that it would not leave”.[12] These aircraft required a high rate of climb to quickly attain their patrol height, but this sacrificed top speed (something which was also hampered by the requirement for a lower landing speed as they operated at night). The Zone fighter concept dominated Air Staff thinking on fighter aircraft for much of the inter-war period.

The people, institutions and ideas governing what was to be needed from a fighter aircraft changed a great deal over the twenty years 1919-1939. Priorities would change constantly. For instance, just some of the priorities were top speed, landing speed, destructive power, pilot view and aerodynamics. Nevertheless, the essence of what a fighter was expected to do remained unchanged: to intercept enemy aircraft and protect friendly ones.

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[11] W. T. S. Williams, "Air Exersises, 1927," *Royal United Service Institution* 72, no. Feb./Nov. 1927 (1927). W. M. Yool, "Air Exersises, 1930," *Royal United Service Institution* 75, no. Feb./Nov. 1930 (1930). F. A. Robertson, "Air Exersises, 1932," *Royal United Service Institution* 77, no. Feb./Nov. 1932 (1932).
[12] Sinnott, *The R.A.F. and Aircraft Design*: p. 17.

WHY THE INTER-WAR PERIOD?

The inter-war period suggested itself for several reasons. Firstly, the historiography upon which part of this thesis is hinged deals largely with its latter years and the years leading to World War Two. Due to this concentration on the mid-late 1930s, there is no real sense of what was going on in the 1920s, or attempts to understand the changes that the technology, and the institutions behind them, went through over the years. Secondly, following the First World War, the British aircraft industry was possessed of some considerable degree of competence and experience. To study the development of aviation technology before the war would be to catalogue the efforts of a number of pioneers each doing their own thing and following their own beliefs. To look at such development during the First World War would be to look at what happens when money is no serious object to research and development, production space, labour, management and so on. In looking at the inter-war years, we can examine a new industry that has just come out of a very considerable baptism of fire (in the case of Britain this baptism came just five years after her first successful flight was conducted). We can examine an industry that had to deal with enormous cutbacks, governmental micromanagement and lacking, for a long time, a fertile market in which to operate.

Furthermore, the twenty years of the inter-war period allows us to look at a protracted period of technological change enabling us to account for the many varied and changing factors influencing the development of British fighter aircraft. Finally, the approach of the Second World War, the danger of Adolf Hitler and National Socialism and the proliferation of the Luftwaffe was not lost on policymakers[13], and

[13] Not least of all the Baldwin government who assured air parity with Germany in 1934 following warnings from Churchill of German rearmament.

so this period also allows us to examine the effects of wider international events on technology.

THE QUESTIONS TO BE ANSWERED

As it will be shown in the section dealing with historiography there has been plenty of work examining the British aircraft industry, individual aircraft and even the technologies which appeared over the twenty years that this thesis covers. However, there has been a great scarcity of work attempting to explain how such technologies appeared, how they linked together and how aircraft technology changed over the period. These are important questions, not only in terms of providing comprehensive explanations for their creation, development and existence but also in providing crucial context when attempting to pass judgement (as many historians have done) on the industry and the technology it created, and the politics and bureaucracy involved in shaping the technology.

Using the example of British fighter aircraft during the 1920s and 1930s, this thesis will look at how the pace of technological change was set. How and why did British fighter aircraft develop the way they did and at the pace that they did? In particular, it will address the central issue of how the shift from the wooden biplane-type fighter of 1918 to the metal monoplane-type of 1939 came about. And can this change be conceptualised as a 'paradigm shift' from one 'technological paradigm' to another?

This is particularly interesting because many consider that aviation now needs to carry out another paradigm shift, due to concerns about environmental impacts, especially as regards climate chaing.

Figure 2 - Sopwith Camel (1917)

Figure 3 - Supermarine Spitfire (1936)

RECORDS AND SOURCES

A major challenge faced by historians of aviation in the 1920s and 1930s is the lack of records from the firms of the industry. As the aircraft firms of the United Kingdom merged in the 1950s and 1960s records were simply thrown out, deemed too expensive to archive. As a result the most common academic discussions of the inter-war aircraft industry tend to focus on the Air Ministry records at the National Archives, Kew, and historians have attempted to judge the efficacy of the Ministry in meeting the needs of the Royal Air Force (RAF) and its various operational requirements, which themselves changed dramatically over time.

This study focuses on Air Ministry records but attempts something different. Rather than judging the Air Ministry, the industry or the RAF in terms of its technological ability, efficiency in research and so on, it attempts to explain how technological changes, both big and small, embodied in RAF fighter aircraft occurred within a wider context and across different levels, i.e., the firm, industry, Air Ministry, RAF and occasionally Government. It must be understood that from the end of the First World War until well into the 1930s the Air Ministry and to a lesser extent the RAF had almost complete control over the way military aircraft were conceived and, thus, an enormous amount of control, tacit or otherwise, over the design of those aircraft.

So, while the primary aim of this thesis is to explain how Britain developed its fighter aircraft between the World Wars, its other major aim is to attempt a different approach to this kind of history. It is a collection of different types of story; in chapter two, for instance, the main focus is the shift from the use of wood to metal in airframe construction and as such takes a major technological shift as its focus. Chapter four, on the other hand, looks in detail at the conception and development of a technical *idea*, in essence, the search for a low-wing monoplane fighter. The aim here is to illustrate the various complexities and evolving nature of the technical development of British fighter aircraft. It does not seek to judge the aircraft industry or Air Ministry, for example, but simply tries to tell the story from a different angle and account for the various factors and influences shaping the technologies, as well as how the whole system[14] of military fighter procurement evolved and was shaped.

CHAPTER OVERVIEW

The thesis is split into five chapters. The first looks at the development of aeronautical technology up to the end of the First World War and provides some context for the later chapters. The remaining four are divided into rough periods of the inter-war years. It was difficult to decide how best to do this as some of the changes talked about span two or more periods.

The first chapter gives a brief overview of the development of aviation in a military context looking at some of the major advancements over the centuries from kites and balloons to zeppelins and finally heavier-than-air craft. This chapter will also examine the influence of the First World War on establishing the wooden biplane as the dominant design, or paradigm, for aircraft.

Chapter two covers the so-called ‘lean years’ of around 1918-1924, and the fight for survival of the Royal Air Force. It is a significant period in the history of aircraft development between the World Wars because it established the RAF as an

[14] By ‘system’ we are talking about the whole array of social and technical factors influencing aircraft development. While by no means an exhaustive list some factors or influences would certainly include: the treasury; specifications; those who formulated specifications; research institutions like the National Physical Laboratory; Air Ministry sub-committees and heads of department; firms of the industry; designers; individuals at firms who decided what to spend money on, like Robert McLean at Vickers; Royal Air Force test pilots; industry test pilots and so on.

autonomous Service, placed Sir Hugh Trenchard firmly in control of aircraft procurement *as well as* defining, to a large extent the operational roles required by the Air Force. Furthermore, it introduces into the story the concept of the Air Ministry 'ring' system, which was another highly significant event in this early post-war period. Essentially, it gave the Air Ministry almost complete control over an aircraft industry whose very survival relied solely on military orders. The extent to which they wielded this control cannot be underestimated and is a thread that is picked up throughout the thesis.

This chapter also presents the first, most substantial part of the wood-metal shift. Following the First World War, this was the first and largest widespread change to occur in British military aircraft. It will be argued that the change itself relied on the creation of a consensus of opinion within the UK aviation community and for the first time shows the extent of Air Ministry control over technical choices made relating to British military aircraft. concerns the influence of doctrine and strategy on developing aeronautical technologies. Finally, it looks at the institutional doctrine, strategy and policy of the Royal Air Force in shaping British military aircraft technology. For instance, it looks at the change in thinking regarding aerial warfare from a strong bomber offensive, supported wherever possible by fighters, to a strong bomber offensive with a counterpart fighter defence for the UK mainland.

The third chapter (1925-1930) finishes the wood-metal story by looking at how the decision to switch to metal was made and how it was actioned by the Air Ministry. The bulk of this chapter, however, is concerned with how the Air Staff planned technical development during peacetime in anticipation of what might be needed in war. This chapter is also concerned with the Schneider Trophy seaplane races of the 1920s and 1930s. It examines the aircraft developed by Supermarine for the contest and tries to show that such competition had a valuable impact on aircraft development in Britain outside of competition aircraft. It examines the story from the perspective of both the designers and the Air Staff, as well as the research establishments. The Schneider Trophy really allowed for the most advanced of aeronautical research to be conducted, although purely in terms of *performance*, not reliability, stability and so forth. Nevertheless, the influence of the contest on the development of military fighter aircraft was significant and therefore worth looking at. It will also contend that the Schneider Trophy *proved* the superiority of the monoplane in terms of performance.[15]

Chapter four (1931-1936) picks up from the previous chapter in continuing to look at how the Air Staff planned during peacetime, but in the early-mid 1930s. This was a time of change at home and abroad. The Air Ministry went through some important changes in personnel, and abroad it was becoming clearer that Germany (and her air force) would be the nation to plan against. This chapter also covers a crucial component of this thesis. Specification F.7/30 was the first time the Air Ministry called for a low-wing monoplane fighter.

It looks at the Royal Air Force/Air Ministry system of aircraft procurement from around 1930-1935. It is highly significant in that such a system involved highly details specifications, in essence, designing an aircraft on paper and asking the industry to deliver it. The Air Ministry's policy was to pick an aircraft on best price and on technical quality. Generally, the aircraft with best performance was chosen, but this chapter tries to look in detail at how a specification was made and how the debates about what performance to ask for were conducted.

[15] Performance being to a large extent the most important aspect of fighter aircraft.

Chapter five examines a much, if not entirely, neglected conference held in 1935. The conference itself was incredibly important and a lot of the highest ranking people in the Air Ministry, research establishments, industry and government attended. The aim of the conference was to discuss how to radically improve the system of research and development as regarding military aircraft. This was a response to the growing realisation that Britain had been left some way behind her potential enemies. Most notably, it must be said, Germany. This chapter will examine the conference in as much detail as possible, firstly, because it has been completely ignored, and also because it is rare to see a document which brings together the thoughts of Lord Rayleigh, Sir Henry Tizard and Sir Hugh Dowding on the one hand, and Frederick Handley Page, Roy Fedden and Arthur Maund on the other. It is a fascinating look at the complexities surrounding aircraft development, research and everything else borne from institutional politics, distrust between the industry and the Air Ministry and so on.

Finally, it will will chart the RAF rearmament programmes of 1934-1939 and some of the technical developments experienced by aircraft in this period. The rearmament schemes are important in that they created something of a technological 'lock in' with regard to aircraft design. The pressure to produce as many aircraft as possible left little time for a lot of the interference on the part of the Air Ministry that had happened in previous years.

Note about the Inter-War Period(s)

It is suggested that it is helpful to think of the 'inter-war years', or 'inter-war period' as it relates to military aviation, not as one single period, but as a succession of four or five smaller phases. The 'lean years' of 1919-1923 are entirely different from the rearamament years of 1934-1939. In between there were several important social, political and economic changes that had enormous impact on aircraft development. The 'Geddes Axe', for instance, slashed R&D funding for aircraft and set development back around 18 months. Staff of the Air Ministry changed over time and many of these changes were highly significant, bringing about their own 'periods'. For example, the retirement of Chief of the Air Staff Lord Hugh Trenchard, and the promotion of his replacement Sir John Salmond changed the way in which aircraft were developed and purchased. As a final example, the increase in funding for aircraft research and development around 1930 heralded yet another change in the way R&D was conducted.

History, Theory, and Methodology

The central issue of this thesis can be put quite simply – 'how did the shift in British fighter aircraft from wooden biplanes to metal monoplanes occur, and why did it take as long as it did? – but addressing this issue is far from simple. This shift in aviation technology could be conceptualised as a 'paradigm shift' or as a 'socio-technical transition', to take two of the most obvious theoretical approaches, but examining the utility of such concepts and their relationship to the historical material presents some potential pitfalls. A key task is to construct a historical account from primary archival sources, but this would be largely shapeless and voluminous if done without a theoretical framing. However, too strong an emphasis on the theoretical concepts runs the risk of constructing a biased historical account.

BACKGROUND: THE HISTORICAL AND HISTORIOGRAPHICAL CONTEXT

The idea for this research originally came about several years ago when researching my undergraduate dissertation regarding the British military aircraft industry and the production of aircraft during World War Two. While reading the secondary literature I was introduced to two now familiar schools of thought regarding the state of the British aircraft industry, scientific and industrial research related to aeronautics, the production of aircraft and the preparedness of the Royal Air Force and the industry to go to war 1939. Although this will be covered in greater detail in the literature review, it is worth noting here to provide a proper context for my choice of conceptual framework.

Since the end of the Second World War right up to the early 1990s, studies of British technological and economic performance in the inter-war and post-WWII period were dominated by what has been termed the 'declinist' school. Scholars of business and economic history such as Correlli Barnett and Martin Weiner held that

Britain's industrial performance, for example, had declined in absolute terms as well as relative to nations such as the United States and Germany over the middle part of the twentieth century. Specifically, when talking about the aircraft industry declinist historians, Barnett most prominently, paint a stark picture of managerial incompetence, industrial frailty, anaemic designs and so on, all governed by a technically incompetent and backwards looking (or at least stagnating) Air Ministry and technical staff.

Declinist history of the aviation industry (and declinist history more generally) has been strongly criticised for judging the Royal Air Force "by the standard of perfection rather than of its peers, and to emphasise failures while ignoring successes and context".[16] Indeed, it is also argued that some recent works on the Royal Air Force "begin by invoking causes which do not exist, continue with arguments based on imagination instead of evidence, and end by describing events which did not happen".[17] Similarly, Leslie Hannah is worried by "…our [Britain's] own brand of counterfactual history…that explains an outcome that never happened…by a cause that is equally imagined".[18]

For instance, a persistent misunderstanding over the effects of the 'ten year rule' has led some scholars to place it firmly at the centre of British defence policy and military spending. The effect, in essence, was that the RAF received "far less money than it needed, by implication far less that other leading air forces dud, and was prevented from developing the forces or the planning needed for major wars".[19] In fact, the idea of the 'ten year rule' as a major factor shaping the pace and

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[16] John R. Ferris, "The Air Force Brats' View of History: Recent Writing and the Royal Air Force, 1918-1960," *The International History Review* 20, no. 1 (1998): pp. 119-20.
[17] Ibid., p. 120.
[18] Leslie Hannah, "Afterthoughts," *Business and Economic History* 24(1995): p. 248.
[19] Ferris, "The Air Force Brats'," p. 120.

development of aeronautical technology has been largely debunked.[20] Despite such strong refutations the 'ten year rule' was a factor, at least in as far as it shaped operational roles. For instance following the First World War there was an emphasis on colonial policing more than defence of Great Britain, one result of this policy was cuts in the Home Defence Force.

Over the last twenty years or so there has been, what has been called a 'decline of declinism'.[21] David Edgerton, prominent amongst the alternative 'revisionist' school, made the distinction between 'absolute' decline and 'relative' decline, central to his thinking. For him, "the appropriate question is why the United States was so much more productive, not why Britain lagged".[22] For revisionists such as Edgerton and Sebastian Ritchie, declinist work proved highly misleading and somewhat dangerous given the influence it wielded. In its, often cursory or heavy-handed, discussion of British aviation it saw failure everywhere, in every aspect of aircraft design, development, management and production. Successes were dismissed out of hand or explained away. There has been an implicit assumption made by declinist historians of aviation that peacetime levels of R&D, production, the urgency and quality of new designs incorporating new technologies should be approaching those during war. Of course, this is not the case as Ritchie points out:

> …the circumstances in which industry has to operate in wartime are often very different from those obtaining in peacetime. War may impose many of its own constraints on industrial production but, conversely, wartime conditions may also offer solutions to problems which might not be easily be solved in peacetime.[23]

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[20] Edgerton, *England and the Aeroplane*.
[21] David Edgerton, "The Decline of Declinism," *The Business History Review* 71, no. 2 (1997).
[22] Ibid., p. 202.
[23] Sebastian Ritchie, *Industry and Air Power - The Expansion of British Aircraft Production, 1935-1941* (London: Cass, 1997). p. 2.

Ritchie also points out that "it is all too easy in the context of Britain's post-war economic problems to explain why Britain did not produce more aircraft during the war. It is much more difficult to show how British industry managed to produce as many aircraft as it did".[24] However, even Ritchie is only really concerned with the expansion of aircraft production beginning in 1935. For declinists and revisionists alike the inter-war aircraft industry and its technology is a useful resource to bolster their arguments. The problem is that there is never any real attempt to understand *how* the technology of this new[25] industry developed.

Opening the 'Black Box' of Technology: Technological Paradigms and Paradigm Shifts

Within the context of this declinist/revisionist historiography the shift from wooden biplanes to metal monoplanes is a key example. For declinists, the shift happened too slowly, thus exemplifying the failings of the British state to nurture and exploit innovation. The overarching question addressed here is: to what extent is this characterisation a simplification?

To answer this requires the documentation of the detailed development of aircraft technology (specifically British fighter aircraft between the World Wars). How did the shifts from wood to metal and biplane to monoplane come about? In what ways were these two technical areas interrelated? To what extent were these technologies adopted more slowly in the UK than elsewhere, and what factors might explain any differential uptake?

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[24] Ibid., p. 3.
[25] 'New' in the sense that immediately following the First World War the British aircraft industry was entirely distinct from the one that entered the War in 1914. It was still learning about everything: design, production techniques, materials, not to mention the forces acting on an aircraft when in flight. By the end of the War in 1918 there was still no universally accepted understanding of how an aircraft stayed up.

Furthermore, at the centre of this issue lies a fundamental question about the nature of technological change. What constitutes a paradigm shift or technical transition? Indeed, how useful is it to conceptualise technological change in terms of paradigms , and or incremental versus radical innovation?

Science and Technology Studies (STS) theorising about the concept of a paradigm has its origins in Thomas Kuhn's *The Structure of Scientific Revolutions* (1962). Kuhn described scientific paradigms as *"…the concrete puzzle-solutions which, employed as models or examples, can replace explicit rules as a basis for the solution of the remaining puzzles of normal science".*[26]

Following Kuhn a number of scholars have adapted the Kuhnian scientific paradigm for use in the study of technology. One of the first, and one with particular relevance to this study of aircraft technology was Edward Constant. In his work on the 'turbojet revolution' – which can be characterised as a paradigm shift from propeller to turbojet-engined aircraft – Constant argues that:

> A technological paradigm is not just a device or process, but, like a scientific paradigm, is also a rationale, practice, procedure, method, instrumentations, and a particular shared way of perceiving a set of technology.[27]

Constant put forward this definition of technological paradigm as part of an alternative explanation of technical change and posited the concept of 'presumptive anomalies'. A presumptive anomaly occurs when advances in science imply "future difficulty for the normal system and the possibility of an entirely new system". For Constant, revolutionary paradigmatic change is for the most part the result of "functional failure" whereby "either the conventional paradigm proves inappropriate to 'new or more stringent conditions' or an individual assumes intuitively that he can

[26] Thomas Kuhn, *The Structure of Scientific Revolutions*, Third ed. (Chicago 1996).
[27] Edward W. Constant II, "A Model for Technological Change Applied to the Turbojet Revolution," *Technology and Culture* 14, no. 4 (1973): p. 554.

produce a better or a new technological device".[28] The difference between a functional failure and a presumptive anomaly is that the anomaly is derived from science and presumed to exist – no functional failure exists.

> What we define here as presumptive anomaly occurs when scientific insight or assumptions derived from science indicate either that under some future conditions the conventional paradigm will fail (or function badly) or that a radically different paradigm will do a much better job or will do something entirely novel.[29]

Constant's view of radical technological change maintains an emphasis on practitioners. In this view "revolution occurs when a significant portion of the relevant community shifts its professional commitment to a new paradigm and begins a new normal technology".[30]

Other scholars, notably Giovanni Dosi, have focussed more on what might be called, in Kuhn's terms, 'normal' technology, the incremental improvement of an existing technology paradigm. Dosi defined a technological paradigm as:

> …"model" and a "pattern" of solution of *selected* technological problems based on *selected* principles derived from natural sciences and on *selected* material technologies.[31]

For Dosi, technological change is the result of technological 'trajectories', which he defined as "the pattern of 'normal' problem solving activity (ie of 'progress') on the ground of a technological paradigm".[32] The trajectory is a "cluster of possible technological directions whose outer boundaries are defined by the nature of the paradigm itself".[33] Dosi also argues that a technological paradigm has "a powerful exclusion effect: the efforts and the technological imagination of

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[28] Ibid.
[29] Ibid., p. 555.
[30] Ibid., p. 556.
[31] Giovanni Dosi, "Technological Paradigms and Technological Trajectories - A Suggested Interpretation of the Determinants and Directions of Technical Change," *Research Policy* 11(1982): p. 152.
[32] Ibid.
[33] Ibid., p. 154.

engineers and of the organisations that are in are focused in rather precise directions while they are, so to speak, "blind" with respect of other technological possibilities".[34]

This concept of technological paradigms that produce 'technological trajectories' through incremental improvement, but that are displaced by new paradigms in paradigm-shifts, has become widely used. In innovation studies it has become typical to speak of a 'dominant design'.[35] For example, Tushman and Anderson argue that "technological progress constitutes an evolutionary system punctuated by discontinuous change" after which "a dominant design emerges".[36]

However, the work of economist Nathan Rosenberg points to one weakness in a view of technical change as characterised by technological trajectories comprising periods of continuous, incremental improvement of paradigms or dominant designs interrupted by radical discontinuities. Rosenberg's classic studies of American machine tool development between 1840 and 1910 suggest a much more complex process in which radical and incremental innovations overlap and in which the former often depend on the latter to succeed.[37] Rosenberg has shown that in the case of machine tools change was a gradual process that was fed by a number of diverse manufacturing industries utilising similar processes using machine tools.

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[34] Ibid., p. 153.

[35] William J. Abernathy and James M. Utterback, "Patterns of Innovation in Technology," *Technology Review* 80, no. 7 (1978). M. L. Tushman and P. Anderson, "Technological Discontinuities and Organizational Environments," *Administrative Science Quarterly* 31(1986).

[36] Tushman and Anderson, "Technological Discontinuities and Organizational Environments," pp. 440-41.

[37] Nathan Rosenberg, "Technological Change in the Machine Tool Industry, 1840-1910," *The Journal of Economic History* 23, no. 4 (1963). Nathan Rosenberg, "The Direction of Technological Change: Inducement Mechanisms and Focusing Devices," *Economic Development and Cultural Change* 18, no. 1 (1969).

> A continuous adoption of established techniques such as automatic operation to new uses, and by a systematic improvement in the properties of materials employed in machine tool processes.[38]

There was, therefore, not one discrete paradigm-shift, but rather many inter-related improvements, some more 'radical' and some more 'incremental'. As Rosenberg notes, a key aspect of this innovation in machine tools was "the cumulative impact of relatively small innovations".[39] So, for Rosenberg, profound shifts in technologies can often take a long time (sixty years in this case) and require many incremental complimentary improvements to be achieved.

More recently, other authors have taken issue with the apparently mechanistic way in which some, notably Dosi, have portrayed the role of paradigms in technological trajectories. For example, although MacKenzie agrees that the Kuhnian scientific paradigm "does…point us by analogy to important phenomena in technological change"[40], he is sceptical of the mechanical analogy implied by Dosi:

> What is wrong [with technological trajectories] is the fundamental idea that technological change can be self-sustaining, that its direction and form can be explained in isolation from the social circumstances in which it takes place.[41]

As MacKenzie and Wajcman note, such an approach does not do full justice to the richness of Kuhn's concept:

> …to do this would be to miss perhaps the most fundamental point of Kuhn's concept of paradigm: the paradigm is not a rule that can be followed mechanically, but a *resource* to be used. There will always be more than one way of using a resource, of developing

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[38] Rosenberg, "Technological Change in the Machine Tool Industry, 1840-1910," p. 433.
[39] Ibid., p. 424, fn 19.
[40] Donald MacKenzie, *Inventing Accuracy - A Historical Sociology of Nuclear Missile Guidance* (MIT Press1990). p. 79, n. 138.
[41] Ibid., p. 167.

> the paradigm. Indeed groups of technologists in different circumstances often develop the same paradigm differently.[42]

MacKenzie and Wajcman note that Kuhn used paradigm to refer to two ‘interrelated by distinguishable’ meanings:

> In the more basic sense, the paradigm is an exemplar, a particular scientific problem-solution that is accepted as successful and which becomes the basis for future work…The paradigm in the first sense of exemplar plays a crucial part in the paradigm in the second, more famous, wider sense of the ‘entire constellation of beliefs, values, techniques, and so on shared by the members of a given [scientific] community.[43]

This thesis will look at the question of why to took Britain longer than some other nations to develop the metal monoplane for Service use. At the end of the First World War the major nations concerned with large-scale aircraft production (Germany, France, the United States and Britain) were working from the same exemplar of the wooden biplane (with some metal monoplanes already in production in Germany). During the inter-war period there was a ‘paradigm-shift’, as the generally (though not exclusively) accepted best aircraft design changes from the wooden biplane of 1918 to the metal monoplane of 1939.

SOCIO-TECHNICAL SYSTEMS AND TRANSITIONS

Although useful, the paradigm concept has limitations in understanding technological change. The emergence of paradigms or dominant designs help explain incremental innovation – what Dosi called technological trajectories – but provides less insight into radical innovation, the process by which one paradigm is displaced by another. As a concept, paradigms help explain stability, but they are less useful in

[42] Donald MacKenzie and Judy Wajcman, eds., *The Social Shaping of Technology* (Open University Press: 2003), p. 9.
[43] Ibid.

understanding change. Moreover, despite the clarifications noted above, a focus on paradigms runs the risk of emphasizing the technical artefact over the socio-technical system.

Thomas P. Hughes' work on 'the system builders' and the electrification of America has utilised a systems approach for the analysis of a particular historical, technological development.[44] Hughes' vocabulary of 'systems' and 'reverse salients' offers us important conceptual tools. It helps us to move away from viewing technology as a single object or artefact such as 'an aircraft', by asking us to be aware of the influence and interplay of components within both the social and technical systems.

At the heart of Hughes' view of innovation is the role of inventor-entrepreneurs, and their ability to combine scientific and technical advances with the necessary enrolment of political and financial support. Hughes' system-builders are thus what Law has termed 'heterogeneous engineers', able to shape simultaneously both the technical and social.[45]

Hughes' notion of the 'reverse salient' is a useful concept for conceptualising some of the changes occurring in aeronautical technology during the inter-war years. For Hughes:

> As technological systems expand, reverse salients develop. Reverse salients are components in the system that have fallen behind or are out of phase with the others. Because it suggests

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[44] Thomas P. Hughes, *Networks of Power - Electrification in Western Society, 1880-1930* (Johns Hopkins1983). Thomas P. Hughes, "Edison and the Electric Light," in *The Social Shaping of Technology*, ed. Judy Wajcman and Donald MacKenzie (Open University Press: 2003). Thomas P. Hughes, "The Seamless Web: Technology, Science, Etcetera Etcetera," *Social Studies of Science* 16, no. 2 (1986). Thomas P. Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems*, ed. Weibe E. Bijker and Trevor Pinch.

[45] John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion," in *The Social Construction of Technological Systems*, ed. Weibe E. Bijker and Trevor Pinch (MIT Press).

> uneven and complex change, this metaphor is more appropriate for systems than the rigid visual concept of a bottleneck.[46]

As an example from Hughes' work on electric light and power systems, engineers may alter the characteristics of a generator to make it more efficient. Due to the changes made in the generator it may be then be necessary to alter the characteristics of another component, such as the resistance, voltage or amperage of a motor, so that it functions optimally with the newly adjusted generator.[47] Thus, in the evolution of a technological system (electric light and power, an aircraft, an aero-engine, manufacturing systems), the adjustment of one component may require the adjustment of numerous other components in order that they might "contribute efficiently to overall system output".[48] A brief illustration of this concept as it applies to this thesis would be the development of aero-engines. Certain components within an aero-engine may be identified as having fallen behind certain others, requiring further development. Notable examples in this case include superchargers for higher performance at high altitude or ducted radiators for increasing thrust and reducing drag. Each was developed differently but in response to problems raised by other improved components.

MacKenzie has noted that the term 'reverse salient' is actually more fitting than:

> …static, mechanical metaphors such as "bottleneck" because it captures the flux, dynamism, and confusion of the process of technological change. Not only can change bring into being reverse salients where previously components functioned satisfactorily…but it may not always be clear where progress is being held up, nor what should be done about it. [49]

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[46] Hughes, "The Evolution of Large Technological Systems," p. 73.
[47] Ibid.
[48] Ibid.
[49] MacKenzie, *Inventing Accuracy*: p. 80.

More recently, Frank Geels and other have expanded on the concept of socio-technical systems, and sought explicitly to understand the factors involved in technological transitions. As it happens, one of Geels' case studies covered the same history as Constant in examining the shift from the propeller to the turbojet in aircraft propulsion systems between 1930 and 1970.[50] Geels has adopted an approach which emphasises the relationship between the co-evolution processes of "markets, user practices, regulation, culture, infrastructure and science"[51] and a multi-level perspective dealing with the three levels of niche, regime and landscape. Geels' argument is that transitions in technology occur when co-evolutionary dynamics at the niche, regime and landscape levels "link up and reinforce each other".

Beginning in the 1930s, Geels identifies the DC-3 passenger aircraft as a new dominant aircraft design which prompted the adoption of a wider socio-technical system consisting of concrete runways (as opposed to grass), radio-based navigation instruments and techniques, greater regulation and new markets. The DC-3 is seen as a result of the alignment of component innovations developed in previous years such as all-metal construction, the mono-wing configuration, retractable landing gears and so on – "the so-called airframe revolution".[52] He identifies various causal links between the innovations adopted for aircraft such as the DC-3 configuration and the socio-technical system. For instance, the heavier DC-3 required that runways were changed from grass to

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[50] Frank W. Geels, "Co-Evolutionary and Multi-Level Dynamics in Transitions: The Transformation of Aviation Systems and the Shift from Propeller to Turbojet, 1930-1970," *Technovation* 26(2006).
[51] Ibid., p. 999.
[52] Ibid., p. 1006.

concrete, which in turn required greater precision in landing procedure and new navigation systems.

However, piston and propeller driven aircraft had limitations at high altitudes and at high speeds. The adoption of the variable-pitch propeller and superchargers were incremental innovations designed to solve these problems. Due to the strong nature of improvement in piston-engine aircraft, regime actors (the Air Ministry for example) had little interest in alternative engines believing that the progress in piston engines would continue.

At the landscape level Geels identifies the approach of the Second World War as the window of opportunity for pioneers of jet engine technology (Frank Whittle, Hans Von Ohain and Herbert Wagner). Increasing defence R&D budgets allowed for more resources for those innovative projects previously thought "impractical". There was increased interest in aero-engines with higher performance allowing Whittle in Britain and Von Ohain in Germany to build a support network to further develop their ideas. By the late 1930s, then, the pioneers of jet technology had created a technological niche for their ideas. Throughout the Second World War this niche for jet technology was adopted for use with interceptor fighters culminating in Britain with the Gloster *Meteor I.* After the War, however, Britain had little money to continue developing military aircraft with jet engines and so concentrated on commercial aviation which was experiencing a strong decline throughout Europe in the immediate post-war years.

In the decade following the War, jet engine technology was developed most strongly in the United States, while Britain concentrated on the more efficient turboprop and by the 1970s commercial aviation had become a "mass phenomenon". Geels has thus attempted to show that technological transitions and transitions in the socio-technical system can occur "not only as technological discontinuities, but as long-run co-evolution processes that also involve changes in markets, user groups, infrastructure, science, culture and regulation".[53]

However, while saying much about the context of technological change there are serious limitations when discussing the content. The focus of such studies is very much at the macro level of technological change at the expense of the micro level. This thesis aims not just to explain how the paradigm shift (or technological transition) in inter-war aircraft technology happened but also to show that certain received wisdom from the inter-war aircraft story might be simplistic.

WRITING HISTORY AND USING THEORY

Writing more than twenty years ago, Edward Constant suggested that:

> It is probably fair to say that more serious historical treatment of technology falls into one of two broad traditions: intellectual and artifactual accounts that have their origins in classical approaches in the history of science, or in biographical and organizational accounts that count business and economic history as their nearest scholarly kin.[54]

In terms of the topic covered here – broadly, the British military aircraft industry of the inter-war years - this largely holds true today. Work is split into examinations of the industry[55], narratives of individual aircraft[56], and biographies of people involved.[57]

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[53] Ibid., p. 1013.
[54] Edward W. Constant, "The Social Locus of Technological Practice: Community, System, or Organization?," in *The Social Construcion of Technological Systems: New Directions in the Sociology and History of Technology*, ed. W. E. Bijker, T. P. Hughes, and T. Pinch (MIT Press, 1987), p. 223.
[55] M. M. Postan, *British War Production* (HMSO: London, 1952). Ritchie, *Industry and Air Power*. Correlli Barnett, *The Audit of War - The Illusion and Reality of Britain as a Great Nation* (London: Macmillan, 1986). Edgerton, *England and the Aeroplane*. David Edgerton, *Warfare State - Britain, 1920-1970* (Cambridge: Cambridge University Press, 2006). Fearon, "The British Airframe Industry and the

Nevertheless, various scholars have produced excellent histories looking into the 'micro'. Some have looked at the change from wood to metal in aircraft structures in the United States[58], some have produced excellent detailed accounts of the development of individual aircraft[59], and others have looked into the complex and complicated process of the development of operational requirements, which are themselves incredibly important tools in shaping an aircraft and embody both social (or political) and technical aspects.[60]

Initially, this thesis was to be based around British industrial capacity and the production of aircraft between the wars, set in the context of the declinist/revisionist debate. It was not until I was exposed to science and technology studies (STS) and was able to concentrate more on the history of technology as a subject area that my focus shifted to what is presented here.

State." Peter Fearon, "The Growth of Aviation in Britain," *Journal of Contemporary History* 20, no. 1 (1985). David Divine, *The Broken Wing - A Study in the British Exercise of Air Power* (Essex: Cheltenham Press, 1966).

56 For example: Alfred Price, *The Spitfire Story*, Second ed. (London: Arms and Armour, 1995). Alfred Price, "Spitfire Prototype and Mark I," *Aeroplane*, no. March (2006). Gordon Mitchell, *Schooldays to Spitfire* (Stroud: Tempus, 2006). Jeffrey Quill, *Spitfire - A Test Pilot's Story* (Crecy, 1996). Also, numerous works covering the aircraft built by a single manufacturer or employed by a specific air force: A. J. Jackson, *Blackburn Aircraft since 1909* (London: Putnam, 1968). D. N. James, *Glostor Aircraft since 1917* (London: Putnam, 1968). Peter Lewis, *The British Fighter since 1912 - Fifty Years of Design and Development* (London: Putnam, 1967). Etc.

57 For example, John Shelton, *Schneider Trophy to Spitfire - The Design Career of R. J. Mitchell* (Sparkford: Haynes, 2008). J. W. Fozard, *Sydney Camm and the Hurricane: Perspectives on the Master Fighter Designer and his Finest Achievement* (Washington D.C.: Smithsonian Institution Press, 1991).

58 Eric Schatzberg, "Ideology and Technical Choice: The Decline of the Wooden Airplane in the United States, 1920-1945," *Technology and Culture* 35, no. 1 (1994). Eric Schatzberg, *Wings of Wood, Wings of Metal: Cultural and Technical Choice in American Airplane Materials* (Princeton1999).

59 For instance, there have been hundreds of *Spitfire* biographies although Price, *The Spitfire Story*.stands apart as a comprehensive account of its development. H. A. Taylor, *Fairey Aircraft since 1915* (London: Putnam, 1974).

60 Sinnott, *The R.A.F. and Aircraft Design*; ibid.

The central theme of this thesis is the switch from the widely used wooden biplane of 1918 to the metal monoplane fighters used by front line RAF squadrons by 1939. The question has been looked at before to greater or lesser extents and covers, for instance, the material and structural revolutions, the development of variable camber wings, retractable landing gears, stressed skins and so on. These innovations have been treated by some historians as if they were developed in a vacuum, as if they followed logical trajectories that 'made sense'.[61]

Applying theory to historical research has been the topic of much debate amongst historians and sociologists of technology. The theoretical options available to the historian or STS scholar are many and varied, each designed to help focus on a particular aspect of a research topic. The danger of relying on one framework to explain weapons development (in our case military aircraft) is that such an approach may not adequately cover the complexity involved in such developments. Furthermore, the strict adoption of a theory may lead to problems in the collection and analysis of data, a tendency to ignore or explain away evidence that does not tick the proper conceptual boxes. Especially, as in our case, one that takes place at different levels (i.e., designer, engineer, firm, Air Ministry, Royal Air Force, Government and so on), and across more than two decades.

While there is a need for a detailed micro approach to understand the changes in inter-war aircraft technology this should not detract from consideration of the macro context in which this shift took place. It will be important therefore, to be aware of the effect each may have on the other. Historians have pointed to the approach of World War Two as the major catalyst of technological change in aircraft.

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[61] Phillip Jarrett, ed. *Biplane to Monoplane - Aircraft Development, 1919-1939* (Putnam: 1997).

One question examined in this thesis is the extent to which this explanation takes account of the groundwork laid well before the War.

Graham Spinardi has suggested that:

> …single factor explanations are not very successful in accounting for the complexity of weapons development. What is clear from previous studies is that both international and domestic determinants can be important, while rarely is either completely irrelevant.

He has also warned against the use of just one model in that theoretical suitability may overrule empirical findings and that fitting the historical narrative into a chosen theory may end up getting rid of any insights gained by the use of a theory in the first place.[62]

Spinardi is not alone in raising such concerns. Various debates have raged between historians and sociologists of technology about the suitability of the use of theory in history.[63] Historians writing on the subject and practice of history have also addressed the question.[64] Generally speaking, these discussions have thrown up two major positions: firstly, historians seem reluctant, if not hostile, to the idea of making use of any strict framework for examining and interpreting data. Secondly,

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62 Graham Spinardi, *From Polaris to Trident: The Development of US Fleet Ballistic Missile Technology* (Cambridge University Press: Cambridge University Press, 1994). p. 15.

63 See R. A. Buchanan, "Theory and Narrative in the History of Technology," *Technology and Culture* 32, no. 2 (1991). John Law, "Theory and Narrative in the History of Technology: Response," *Technology and Culture* 32, no. 2 (1991). Nick Clayton, "SCOT: Does it Answer?," *Technology and Culture* 43, no. 2 (2002). Weibe E. Bijker and Trevor J. Pinch, "SCOT Answers, Other Questions," *Technology and Culture* 43, no. 3 (2002). Hayden White, "The Question of Narrative in Contemporary Historical Theory," *History and Theory* 23, no. 1 (1984). J. H. Goldthorpe, "The Use of History in Sociology: Reflections on some Recent Tendencies," *British Journal of Sociology* 42(1981). C. W. Mills, "Uses of History," in *The Sociological Imagination*, ed. C. W. Mills (Oxford: 2000).

64 John Tosh, *The Pursuit of History* (London2006). Ludmilla Jordanova, *History in Practice* (Hodder2006). N. B. Harte, ed. *The Study of Economic History* (Cass: 1971). ibid., See Peter Mathias, 'Living with the Neighbours: The Role of Economic History'. Robert Harrison, "History and Sociology," in *Making History: An Introduction to the History and Practices of a Discipline*, ed. Peter Lambert and Phillipp Schofield (Routledge: 2004).

sociologists of technology are keen to make use of theory in historical studies of technology, whilst bristling at the suggestion that the theoretical frameworks they advocate are detrimental to historical practice. Simply put – for sociologists, historians have misunderstood the nature of theory, and as historians see it, sociologists want to force historical evidence into a rigid framework.

Buchanan has argued that it is time to reassert the importance of narrative in writing about the history of technology.[65] His charge is that there has been too much focus on the theoretical and he states, for instance, that Thomas Hughes' approach "adds little to the comprehension of what is, essentially, good old-fashioned narrative history".[66] However, although for the most part historians are reluctant to use theoretical frameworks, they have nevertheless been implemented with some success.

I believe that historians can go further, however, by making use of concepts put forward in the field of STS. I think the most realistic way for historians to look at the use of theory can best be shown in a quote from economic historian Thomas Cochran:

> …since theory must be either implicit or explicit, it is better for scholarly purposes that it should be explicit. Carefully formulated theory restricts unconscious bias, gives meaning to otherwise formless data, and is more likely to reveal unexpected relationships.[67]

In a similar vein, Diane Vaughan has noted that:

> We choose a case because we have good theoretical and empirical reasons to think it might be an example of x. The analysis can be developed from ethnography, interviews, original documents, or secondary analysis. Some theoretical logic is always part of our selection,

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[65] Buchanan, "Theory and Narrative," p. 365.
[66] Ibid., p. 369.
[67] Thomas C. Cochran, "Theory and History," *The Journal of Economic History* 3(1943).

> either implicitly or explicitly, so first we want to make it explicit, then we use it as an heuristic device to guide the analysis and organize insights.[68]

Ideally, historians must be possessed of adequate theoretical frameworks to guide the process of data collection and then, in turn, to interrogate that data. Generally speaking, the historian adopts a more implicit approach to the use of theory which may result in unconscious, or perhaps even sometimes conscious, bias. Occasionally, there is a tendency to be highly selective and ignore or explain away evidence which does not fit with the historian's view of the subject. Such an inclination might account for the kind of history written by declinist historians (indeed, there is also a tendency within the revisionist school to ignore or explain away obvious problems in design, production or management for instance). This tendency is brought about, I suspect, from the kinds of questions posed in historical work, or in basing arguments upon a faulty premise. Vaughn has also suggested that:

> Perhaps the guiding theory is better thought of as an analytic framework that opens possibilities at the same time that it focuses the research...which forces us to take into account and integrate all data that bear on the incident or activity in question.[69]

I think it is fair to say that often it is the case that some historians are not guilty of inaccuracy,[70] but of constructing stories from evidence in a selective way and thus producing an account that may be said to be both accurate *and* misleading. To qualify this statement further I will use an example from Barnett's *Audit of War*.

> …on 25 June 1919, three days before the signing of the Treaty of Versailles appeared to seal the German eclipse as a power…the first all-metal cabin monoplane, the Junkers F-13…made its maiden flight in Germany. The F-13…became the most widely used transport aircraft in the world during the 1920s. It was followed in 1931 by the Junkers 52 three-engined all-metal

[68] Diane Vaughn, *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at N.A.S.A* (Chicago: University of Chicago Press, 1996). pp. 456-57.
[69] Ibid., p. 457.
[70] Carr, quoting Housman, noted that for historians 'accuracy is a duty, not a virtue'. E. H. Carr, *What is History?* , 2nd ed. (Palgrave Macmillan2001). p. 5.

> monoplane…In 1927 the Lockheed Vega, designed by a German engineer, pioneered light monocoque construction. In 1932 [there] appeared in the United States…the Douglas DC-1, a fast, twin-engined, low-winged, all-metal, stressed-skin monoplane…*This was the technology that was to lead to the first generation of high-speed all-metal monoplane military aircraft, such as the Junkers 87 dive-bomber, the Heinkel 111 and the Dornier 17 medium bombers, all of which reached squadron service with the Luftwaffe in 1936, and were faster than biplane fighters then forming the frontline strength of the RAF.*[71]

This statement, while factually correct, completely ignores several important points about RAF re-armament policy in the mid-1930s. Barnett leads the reader to believe that in 1936 the Luftwaffe's bombers were faster than the RAF fighter aircraft and that because of this (and fitting in nicely with his overall argument) British technology and technology policy were backwards and out of date. Though it is an obvious example, he fails to point out that the British effort in racing sea-planes was, in fact, some years ahead (in terms of speed and aerodynamics) of his German example. The all-metal stressed-skin racing monoplanes[72] built by Supermarine for the Schneider Trophy contained all the technological virtues he felt were lacking in Britain.

Furthermore, he makes no mention of another Supermarine success, the *Spitfire*, which was again an all-metal, stressed-skin, low-winged monoplane (first flown in 1936)). The simple fact is that by as early as 1934 the Air Ministry had begun, in earnest, plans to modernise the RAF and in so doing replace many aircraft considered obsolete at the time by purchasing large numbers of the new *Spitfire* and the Hawker *Hurricane*. So Barnett, like certain other historians to greater or lesser extents, can be said to be both accurate in his facts but misleading in his claims.

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[71] Barnett, *Audit of War*: p. 129 (emphasis added).
[72] The S.4, S.5, S.6, and S.6b.

I do not wish to suggest that this is a problem from which all historians suffer, or to suggest that to be misleading is some sort of historians' disease. But the fact remains that to label oneself as a 'declinist' or 'revisionist' does betray a particular view of the historical world, which carries with it many assumptions and preconceptions as to the way events happened. To be a declinist in the vein of Correlli Barnett for example means believing in the idea of a British industrial decline in the latter half of the nineteenth century and early twentieth century. This belief is then reflected in his savage portrayal of British industrial competence. Thus, evidence to the contrary, such as consistently rising aircraft export and production figures, or improvement in aircraft technology is completely ignored or explained away.

Going back to Angus Buchanan, however, who states that:

> …the imposition of an alien conceptual vocabulary on the subject matter of history is misleading, causing obfuscation and unjustified selectivity in the use of historical evidence. Evidence, the reader feels, is welcome when it fills the preconceived conceptual boxes and is otherwise likely to be discarded.[73]

But while Buchanan's criticism is levelled at the use of social science theory in narrative history, this is precisely the problem with historical works which are devoid of any explicit theory to help shape the questions and to limit on occasions the data we look at. John Law, in response to Buchanan, suggested that his critique of social science theory in the history of technology stemmed from the idea that social science theory and narrative history are "driven by different kinds of concerns and interests".[74] Assuming that is true I have tried to find my own blend of narrative and theory based upon my concerns and interests.

[73] Buchanan, "Theory and Narrative," p. 370.
[74] Law, "Theory and Narrative: Response," p. 378.

So on the one hand there is a desire to make good use of theory, while on the other is the concern that too much theoretical rigidity runs the risk of an incomplete or misleading story. Thus, at this stage my position regarding the use of theory is to borrow concepts from theories that I think will be useful based on the particulars of my topic and period.

THEORY AS METHODOLOGY

This research thus draws on broader STS theory to guide the methodological approach used to carry out the research and construct the historical accounts. The concepts I have chosen are from a variety of STS theories and have been selected based upon their suitability for adoption within a historical methodology, as well as for their critical capacities in dealing with both technical and social elements and complexity. The theories I have drawn upon are Actor-Network theory (ANT), the social construction of technology (SCOT), socio-technical systems and the Sociology of Scientific Knowledge (SSK).

The first concept that I have tried to bear in mind is from the Sociology of Scientific Knowledge. 'Symmetry' asks us to treat both success and failure equally and to "…seek the same kinds of causes for both true and false [and]…rational and irrational beliefs".[75] Trevor Pinch and Wiebe Bijker adopted the symmetry principle for SCOT:

> Given our intention of building a sociology of technology which treats technological knowledge in the same symmetrical, impartial manner that scientific facts are treated within the sociology of scientific knowledge, it would seem that much of the historical material does

[75] David Bloor, *Knowledge and Social Imagery* (Chicago1991). pp. 175-79.

> not go far enough. The success of an artefact is precisely what needs to be explained. For a sociological theory of technology it should be the explanandum, not the explanans.[76]

This particular concept is important for avoiding the assumption that failed technologies were doomed from the outset, and similarly, that successful technologies had success written into them from the beginning. In short, it should help the historian of technology avoid the assumption that technological development is autonomous.

For instance, it may help us explain why the monoplane was first dropped in favour of the biplane (around 1913) and then reintroduced some twenty years later as the dominant design for military aircraft. On a smaller scale there is also the issue of new designs for the Royal Air Force. With each specification for a new aircraft from the Air Ministry there were at least four designs submitted and at least two or three prototypes built for Service trials. Most of the time just one of these designs was chosen for Service use and so there were many choices made in the selection of new aircraft.

Actor-Network theory and the Social Construction of Technology were developed during the 1980s to explain the creation, development, success and/or failure of technology and scientific knowledge. From ANT[77] I want to make use of the concept of 'heterogeneous engineering', whereby the technical and social are simultaneously shaped by, say, an actor or institution.[78] I have chosen it because successful engineers, such as Thomas Edison (or in the world of aviation Reginald Mitchell or Sydney Camm) had to be able to engineer both the social and the material.

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[76] Wiebe E. Bijker and Trevor J. Pinch, "The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," *Social Studies of Science* 14(1984): p. 406; ibid.

[77] Actor-Network theory is a theory of the relationships between 'things' and 'concepts'. Applied to technology studies, ANT is perhaps most usefully employed in describing the interactions between people, ideas and technology.

[78] Law, "Technology and Heterogeneous Engineering."; ibid.

The story of aircraft development between the World Wars is replete with both actors and institutions that might be termed heterogeneous engineers. I have used this concept to help frame some parts of the story such as the Aeronautical Research Committee which helped to shape both the political and technical landscape by advising the Air Ministry on one hand, and directing aeronautical research and advising the industry on the other.

The next concept I have made use of independently from its larger SCOT framework is 'interpretive flexibility' which points out that artefacts mean different things to different actors, and further, that technical development raises new problems to be negotiated and solved. This concept was again chosen to focus attention on the highly social nature of technological change and the almost constant negotiation of the development of a technology. Stewart Russell has pointed out that:

> …interpretive flexibility may allow us to explain how groups relate the potential of an artefact to their objectives, and provide a basis…for interpreting statements in historical records...[79]

The amount of historical records that I have used has meant that this concept has been useful in mapping out the interests that varying groups or individuals have in the technology and the differing requirements those groups may have of the technology.

METHODOLOGY

The bulk of this research was carried out at the National Archives, Kew and the National Aerospace Library at Farnborough. Due to the time period covered in the thesis (1918-1939), certain types of data collection were necessarily excluded. I could not rely on interviews as a source, and so I had to work with archives, contemporary publications and secondary literature.

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[79] Stewart Russell, "The Social Construction of Artefacts: A Response to Pinch and Bijker," *Social Studies of Science* 16, no. 2 (1986): p. 343.

The National Archives

The National Archives in particular, were a very useful and fruitful source for conducting this research. As the aircraft firms of the British industry merged or went out of business in the 1950s and 1960s the records of these businesses were simply thrown out, deemed too expensive to keep. In a sense though, they were not essential as the Air Ministry played a singularly important role in shaping and developing military aircraft technology throughout the 1920s and 1930s. Therefore, the holdings of the National Archives (in particular AIR – records created by the Air Ministry, Royal Air Force and related bodies and AVIA – records created or inherited by the Ministry of Aviation) were central in constructing the history of the participation of the government. What little we can gather from the firms through these holdings are glimpses of correspondence, agreements, contracts, designs and so forth.

The data taken from the National Archives was chosen based on its content pertaining to design, policy relating to the industry, management of the industry, the technology that might be required by the Royal Air Force and why, the strategy and policy of the Royal Air Force and so on. Because this thesis is not interested in levelling normative judgements at the performance or 'quality' of the industry, Air Ministry, technology and so forth, records discussing production figures, industry performance and the like were largely ignored. Anything that might shed light on *how* military aircraft technology developed in the inter-war years was chosen.

National Aerospace Library, Farnborough (The HUB)

I was fortunate to be introduced to the head librarian Brian Riddle who was a great help to me during my work there.

Mainly, the HUB was used for secondary literature, but there were a number of useful sources, such as the entire proceedings of the Royal Aeronautical Society (RAeS) and the technical reports and memoranda of the Royal Aeronautical Establishment (RAE) at Farnborough.

Limitations of Data Collected

Perhaps unavoidably, there are limitations to my data collection. Some of which were imposed upon me (the destruction of company records for instance), while others were due simply to time, space and cost issues. Concentration on Air Ministry archives might be considered a limitation in looking, as it does, at one side of the topic. However, the extent of control exercised by the Ministry in the inter-war years was such that I do not consider it to be as limiting as might be supposed.

Again, time spent at the HUB was time spent looking at the most promising publications and proceedings of the RAeS.

Strengths of Data Collected

I have tried wherever possible to bring into this thesis data which has been previously ignored or deemed unimportant. The fact that my thesis focuses on something different from what has gone before in terms of British military aviation technology means that I have been able to use a lot of the archive holdings in a different way. For example, the files pertaining to Air Ministry specification F.7/30 (the first conscientious search for a low-wing fighter monoplane) have been used in this thesis to try and explain exactly why the Air Ministry deemed such a search to be important and how they went about it. It is interesting to note that in Barnett's *Audit of War* the chapters looking at aircraft contain very little research from the Aviation Ministry

(AVIA), none at all from the Air Ministry (AIR) and almost everything else from Cabinet files (CAB). How can one take seriously a critique of technology without any serious attempt to look at the relevant files?

Chapter One: Early Developments in Military Aviation

The earliest man-made flying machines bore little resemblence with their more successful cousins which appeared between 1903 and 1910. Yet, the principles formulated from the use of such early inventions were at the core of the first gliders and later powered machines in the late nineteenth and early twentieth centuries. Kites capable of lifting a human being were used in China as early as 1000 B.C., and its form was used as the wings of Sir George Cayley's first model glider in 1804.[80] The European style windmill, first emerging in illustration in *c.*1290 with its horizontal spindle has been claimed to be the "passive ancestor of the active aircraft airscrew".[81] Still further, it has been suggested that children's toys of the same era based upon the windmill worked in precisely the same way as a helicopter and were the active ancestor of the airscrew.[82] To detail the lineage of these inventions and how they came to bear on the experiments in aviation of the sixteenth, seventeenth, and eighteenth centuries would take far too long and divert from our primary purpose here, which is to discuss the evolution of the first heavier-than-air craft, and their use in a military context.

If the glider experiments of Cayley,[83] Otto Lilienthal,[84] Clement Ader[85] and S. P. Langley[86] (to name just a few) were the first concentrated efforts to achieve

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[80] Gibbs-Smith, *Aviation - An Historical Survey*: p. 3.
[81] Ibid.; ibid.
[82] Ibid.
[83] Sir George Cayley (1773-1857). One of the most significant figures in the development of modern aviation, his work influenced the pioneers of the late nineteenth and early twentieth centuries. Perhaps most notable Orville and Wilbur Wright.
[84] Otto Lilienthal (1848-1896). German aviation pioneer. Conducted and documented a number of successful flights using gliders. His experimental approach followed that established by Sir George Cayley. Authored *The Problem of Flying* (1893). Killed in a glider accident.
[85] Clement Ader (1841-1925). French Inventor and engineer who constructed his first 'flying machine' in 1886 along with a lightweight steam engine of his own design to

sustained, controlled and powered flight in a heaver-than-air craft, then the balloons and dirigibles of von Zeppelin, the Montgolfier brothers and Thaddeus Lowe marked the importance of altitude in a strategic military setting. A brief look at the story of balloons and dirigibles is enough to demonstrate their importance in persuading many militaries[87] of the value of using lighter-than-air craft to achieve a tactical advantage over their enemies. It is important to note that these principles were adopted in Britain decades before military aircraft were to be built.

CAYLEY AND CRYSTALLISING THE 'PROBLEM OF FLIGHT'

Sir George Cayley (1773-1857) has been described by French historian Charles Dollfus as "the true inventor of the aeroplane and one of the most powerful geniuses in the history of aviation".[88] And further, that, "the aeroplane is a British 'invention'; it was conceived in its entirety by George Cayley". His work on aerodynamics in the decade 1799-1809 was to provide the foundation upon which "the whole vast science of flying is founded".[89]

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power it. Published *L'Aviation Militaire* in 1909: "An airplane-carrying vessel is indispensable. These vessels will be constructed on a plan very different from what is currently used. First of all the deck will be cleared of all obstacles. It will be flat, as wide as possible without jeopardizing the nautical lines of the hill, and it will look like a landing field".

[86] Samuel Pierpont Langley (1834-1906). American astronomer, physicist and pioneer of aviation. Experimented with rubber-band powered models and gliders around 1887. Largely unsuccessful.

[87] Most notably, the United States, the United Kingdom and Germany.

[88] C. H. Gibbs-Smith, *The Invention of the Aeroplane, 1799-1909* (London: Faber & Faber, 1966). p. 5.

[89] Gibbs-Smith, *Aviation - An Historical Survey*: p. 23.

Sir George Cayley

Furthermore, his work in this decade crystallized the conundrum of aviation: "The whole problem is confined within these limits, *viz.* to make a surface support a given weight by the application of power to the resistance of air".[90] The research and work conducted by Cayley attempted to "cover those four main subjects that were – and must remain still – central to any reputable aeronautical curriculum: propulsion, structure, aerodynamics, and stability and control".[91]

Cayley's work influenced most of the pioneers that would follow him. His methodology was used by Lilienthal to great effect and, indeed, many of the early pioneers believed Cayley to be the father of aviation. Victor Tatin,[92] writing in 1907:

> "In following the chronological order, one finds, at the head of the inventors of the aeroplane Sir George Cayley; this man of genius...the masterly work of Cayley".[93]

Another similar example is that of Alphonse Berget:

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[90] Gibbs-Smith, *The Invention of the Aeroplane, 1799-1909*: p. 7.
[91] J. A. D. Ackroyd, "Sir George Cayley, the Father of Aeronautics, Part 1: the Invention of the Aeroplane," *Notes and Records of the Royal Society of London* 56, no. 2 (2002): p. 171.
[92] Victor Tatin (1843-1913). French inventor who created the first model aeroplane to achieve takeoff under its own power in 1879.
[93] C. H. Gibbs-Smith, *The Rebirth of European Aviation, 1902-1908* (London: HMSO, 1974). p. 210.

> This inventor, the incontestable precursor of aviation, was an Englishman, Sir George Cayley…the name of Sir George Cayley should be inscribed in letters of gold at the beginning of the history of the aeroplane.[94]

Even Wilbur Wright writing in 1909 said:

> About 100 years ago an Englishman, Sir George Cayley, carried the science of flying to a point which is had never reached before and which it scarcely reached again during the last century.[95]

His contributions, though separated from the first practical flights by a century, should not be underestimated. Gibbs-Smith's *Aviation – A Historical Survey* fairly credits him with being the first man in history:

i. To divorce the system of thrust from that of lift, and so inaugurate the concept of the modern fixed-wing powered aeroplane;
ii. To use a whirling arm for aeronautical research;
iii. To use model gliders for aerodynamic research;
iv. To design, build and successfully make to fly, proper aeroplanes (unpowered) in the form of both model and full-size man-carrying machines supported by fixed wings, stabilized by an adjustable tail-unit and wing-dihedral[96], and controlled by a combined elevator and rudder;
v. To formulate and to publish the basic aerodynamics of the fixed-wing aeroplane, including longitudinal and lateral stability…and to apply this to both model and full-size man-carrying aeroplanes;
vi. To surmise that a cambered aerofoil gives greater lift than a flat one;
vii. To design, build and apply a light cycle-type undercarriage;
viii. To suggest an internal combustion engine for aircraft propulsion.[97]

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[94] Ibid., p. 211.
[95] C. H. Gibbs-Smith, "Sir George Cayley: 'Father of Aerial Navigation', 1773-1857," *Notes and Records of the Royal Society of London* 17, no. 1 (1962): p. 53.
[96] The upward tilt of aircraft wings and tailplanes.
[97] Gibbs-Smith, *Aviation - An Historical Survey*: pp. 23-24. Gibbs-Smith's complete list is not reproduced here as it is simply too long.

The direct significance of Cayley's work to this thesis, although separated from the inter-war years by over a century, is that he laid down and 'crystallised' many of the problems and questions to which answers and solutions were being sought throughout the 1920s and 1930s – in many respects the solutions of that era are still being improved upon today. It is interesting to note, that throughout the 1920s the whole question of how an aircraft flew was still being debated.[98]

Balloons and Dirigibles

The origins of the use of aircraft as a military technology undoubtedly lie in the development of air balloons as observation posts for various armies. The idea of using altitude as an aide in warfare originated in China, and the first example for which we have adequate evidence occurred in around 206 B.C. when kites were used to determine the distance between an army and its target.[99] It was 1783, however, before the first manned ascent in a balloon took place. Invented by the Montgolfier brothers in France, balloons were pioneered as military aids in the United States during the American Civil War (1861-1865) by Thaddeus Lowe amongst others; Lowe perhaps being the most famous, or notorious depending on one's point of view.

Lowe's balloons could ascend to around 1,000 feet, and report observations by telegraph on troop movements over three miles away and thus were considered highly effective.[100] Balloons were also used with great success in the direction of artillery fire during the American Civil War. Before the conflict ended, however, interest in

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98 David Bloor, *The Enigma of the Aerofoil - Rival Theories in Aerodynamics, 1909-1930* (London: University of Chicago Press, 2011).
99 Robert Jackson, *Army Wings: A History of Army Air Observation Flying, 1914-1960* (Pen and Sword Aviation2006). p. 7.
100 E. B. Block, *Above the Civil War: The Story of Thaddeus Lowe, Balloonist, Inventor, Railway Builder* (Howell-North1966). C. D. Ross, *Trial by Fire: Science, Technology and the Civil War* (White Mane2000).

aeronautics died thanks in large part to Lowe's resignation from the Balloon Corps[101] and would not be resurrected in the United States for some thirty years.

Balloons were used as observation tools throughout the armed forces of Europe and particularly in Germany. The change from balloons to rigid airships capable of being steered (hence, dirigible), as opposed to the tethered balloons (or 'captive balloons') used in the latter half of the nineteenth century originated in Germany by Lieutenant General Count Ferdinand von Zeppelin. He was a balloon enthusiast and upon leaving the German army in 1898 he was determined to build efficient rigid airships. The first, 420 feet long, was completed in 1900.[102] By 1908 Britain had just begun its own concentrated dirigible airship programme. They had been enthusiastic about developing balloon technology for forty years however, with experiments at the Woolwich Arsenal in 1878, and from 1894 there had been a Balloon factory at South Farnborough, the forerunner of the Royal Aircraft Factory, which later became the Royal Aeronautical Establishment.[103] It is worth noting here that before 1912 when the Royal Flying Corps was established, the British military had no dedicated flying Service. Instead, the Admiralty and War Office were involved in developing aviation for their respective Services.

British work on aeronautics was not quite as fragmented as that of the United States and as mentioned above Britain was enthusiastic for the technology. After the establishment of the Balloon Equipment Store at Woolwich, the first British balloon was used in 1879 and then in 1880 it was used in military manoeuvres before being

[101] His Balloon Corps was transferred to the Corps of Engineers and a 40 per-cent pay cut was imposed causing Lowe to resign in protest. Thus, it was neither a failure of technology or an institutional one that caused the Balloon Corps to be disbanded. That being said, Lowe was also to blame for establishing a monopoly within the Union Army, failing to support other balloonists requiring aid from his Corps. When he resigned there was, therefore, no one to fill the gap he left.

[102] P. M. Brooks, *Zeppelin: Rigid Airships, 1893-1940* (Smithsonian1992).

[103] J. D. Scott, *Vickers - A History* (London1963). p. 69.

taken, in 1884, on an expedition to Botswana.[104] Balloons were used with further success in the Boer War of 1899-1900. Their value on the battlefields of South Africa went a long way to convincing certain British Army officers that aerial reconnaissance was a legitimate concern and could be developed further into a valuable asset.[105]

The first British airship (the *Nulli Secundus*) flew in 1907, and opinions were divided amongst the officers of the armed Services. Some were skeptical of the new technology, while others believed that in light of the German head start, Britain should begin further development of airships with an aim to integrating them into the Services as soon as possible. J. D. Scott has noted that there was a sharp division in the opinions of the Admiralty over airship development:

> The Admiralty…had been looking with interest at Zeppelin's achievements, but they were by no means in a hurry. Many admirals regarded airships as they had regarded submarines, with hostile skepticism; others felt that anything a German cavalryman could do British sailors could do better in their own good time. But a number of officers felt differently…These men…had that particular type of enthusiastic, dissident, thrusting Service temperament…They were the same men who had backed submarines [in the face of opposition some years previously]…[106]

In July 1908 proposals were submitted for what was to become the first Naval Air Service. The proposals were that a Naval Air Assistant should be appointed to the Admiralty, that the War Office should make advice from the Balloon School available to the Admiralty, and that Vickers Sons and Maxim should be consulted about the design of a rigid airship for Naval use. Vickers, a company traditionally engaged in

[104] Jackson, *Army Wings*: p. 13.
[105] Ibid., p. 15.
[106] Scott, *Vickers*: p. 70.

the design and manufacture of steel, guns and gun turrets was thus being asked to change their thinking from the design of these products to those of silk and light alloy.

The most important argument in favour of airships, as far as the Admiralty were concerned, was the notion that they could, if necessary, undertake an emergency descent at sea.[107] This lay at the root of the Admiralty's policy of concentrating on airships rather than heavier-than-air craft. It took Vickers two years to construct the *Mayfly*. Tragedy struck, however, when she broke her back while being brought out of her shed. This added an important string to the anti-air movement bow, and it was also becoming clear that when the British air Services were eventually established, they would depend mainly upon aircraft.

THE WRIGHT STUFF (!)

Orville and Wilbur Wright were the first aviators to achieve a sustained flight in a heavier-than-air craft. Their interest in aviation was first aroused by the work, and dramatic death of the German glider pioneer Otto Lilienthal.[108] Their very early work convinced them that Lilienthal's method of control, based solely on body-movement, was inefficient. They built their first aircraft, a biplane kite with a span of five feet, in 1899 to test the virtue of wing warping as a method of control in unsteady winds.[109]

Being appraised as a successful method of control, they decided to build a full-scale glider, adopting the wing warping method as soon as possible, eventually finishing in September 1900. This glider had a span of 17 feet and 165 sq. ft. area. The Wright brothers were conspicuous in that their approach to design and development lay in some scientific reasoning and the use of experiments with wind

[107] Ibid., p. 71.
[108] C. H. Gibbs-Smith, *The Wright Brothers - A Brief Account of their Work, 1899-1911* (London: HMSO, 1987). p. 4.
[109] Ibid., p. 5; ibid.

tunnels, as opposed to the cut and try empiricism of other pioneers. Initially, the brothers followed the work of Lilienthal and others in order to calculate the lift generated by their wing sections, but came to realise that much of the data might be flawed. As Wilbur put it:

> Having set out with absolute faith in the existing scientific data, we were driven to doubt one thing after another, till finally, after two years of experiment, we cast it all aside, and decided to rely entirely upon our own investigations.[110]

The glider experiments conducted by the brothers led to many modifications to their design, both major and minor. The brothers also developed their own aero-engine and propellers which both went through several changes, and after overcoming several problems with broken drive shafts and bad weather they made their first controlled, sustained and powered flight on the 17th December 1903 at Kill Devil Hills near Kitty Hawk, North Carolina.

Having achieved this goal, the brothers decided to offer their machine to the United States government. Due to several unforeseen circumstances, the letter intended for William Howard Taft, the Secretary of War, ended up being delivered to General Gillespie at the War Department's Board of Ordinance and Fortification, who misunderstood the intentions and achievement's of the Wrights and wrote to them, via their go-between Congressman Robert Nevin that:

> It appears from the letter of Messrs. Wilbur and Orville Wright that their machine has not yet been brought to the stage of practical operation, but as soon as it shall have been perfected, this Board would be pleased to receive further representations from them in regard to it.[111]

The consequences of this misunderstanding were that the brothers simply looked elsewhere for a buyer for their machine. The first country to express an interest in

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110 Ibid., p. 6.
111 Alfred Gollin, "The Wright Brothers and the British Authorities, 1902-1909," *The English Historical Review* 95, no. 375 (1980): p. 301.

purchasing the Wright *Flyer* was the United Kingdom. There was an unusually close relationship between the Wright brothers and several prominent aviators and aviation enthusiasts in Britain: Lieutenant-Colonel John Capper of the Balloon Section of the British Army; Patrick Alexander, a prominent member of the Aeronautical Society of Great Britain who sought out the Wrights as early as 1902 upon learning of their experiments with gliders and Major B.F.S. Baden-Powell of the Scots Guards, an authority in the field of military aviation.[112]

By 1905 these relationships, bolstered by an overwhelmingly favourable impression of the brothers by everyone involved in British aeronautics,[113] encouraged the Wrights to enquire if the British government would consider purchasing the machine along with the "scientific and practical knowledge and instruction we are in a position to impart".[114]

HALDANE AND THE EARLY BRITISH 'SCIENTIFIC APPROACH'

An important figure in the British government's dealings with the Wright brothers was Richard Burdon Haldane who became the British Secretary of State for War in 1905.[115] It was Haldane who would ultimately decide whether or not to purchase aircraft from the Wright's in view of the aeronautical situation in Britain. Indeed, his decision to not use the Wright brothers caused damage to his reputation and he was largely a victim of media and public enthusiasm for aviation which saw his refusal to

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112 Ibid., pp. 294-96.

113 Ibid., pp. 293-94. Lt. Col. Capper, for example, had this to say: "…they have something to be even more proud of than their great invention, and that is their simple-minded honesty and kindness…This is most delightful…to find people so utterly unaffected and unspoilt".

114 Ibid., p. 302.

115 Alfred Gollin, "The Mystery of Lord Haldane and Early British Military Aviation," *Albion: A Quarterly Journal Concerned with British Studies* 11, no. 1 (1979): p. 46.

do business with the Wrights as backwards thinking. However, his position on aviation was far more complex than has been assumed by certain historians in the past. For example, he has been lambasted as "the apostle of military stagnation" by E. Charles Vivian[116] and has been accused by Marvin McFarland as having caused England to miss "the aviation bus as completely as Neville Chamberlain was to miss another bus at a subsequent stage of world history".[117] These criticisms, however, have failed to take proper account of the complexity of the situation in 1905-1910.[118] The situation was so complex that it has been noted that "Haldane's actions behind the scenes may never be known with certainty".[119]

Haldane was responsible, however, for helping to develop a rigorous scientific approach to developing aviation in Britain with a strong emphasis on the stability of aircraft in flight. In May 1909, he reported to the House of Commons that he was to be working with the director of the National Physical Laboratory (NPL), Lord Rayleigh and Dr. Richard Glazebrook to discuss developing the Air Services. The direct result of this was the appointment of the Advisory Committee for Aeronautics, presided over by Rayleigh: "The idea was to bring the "highest scientific talents" to bare on the aeronautical problems of the army and navy".[120]

He still regularly came under fire in the House of Commons and was accused of being "hypnotized by the blessed word 'Science'".[121] The major criticism levelled

[116] E. Charles Vivian, *A History of Aeronautics* (New York1921). p. 176.
[117] Marvin McFarland, "When the Airplane was a Military Secret," *The Air Power Historian* 2, no. 4 (1955): pp. 78-79.
[118] Haldane was determined to follow the German example, or at least emulate their scientific approach. He also was aware that stability in the air would be crucial and that the Wright brothers machine required constant adjustments on the part of the pilot to keep it stable.
[119] Percy Walker, *Early Aviation at Farnborough*, 2 vols., vol. 1 (London1971). p. 254.
[120] Gollin, "Mystery of Lord Haldane," p. 62.
[121] Ibid.

at Haldane was that he was not sufficiently practical. In August 1909 Lord Lee of Fareham, chairman of the Parliamentary Aerial Defense Committee, argued that:

> Instead of devoting our energies so exclusively…to the study of pure theory, we ought to go further than we have done in…purchasing accumulated experience that is being gained in other countries.[122]

The 'accumulated experience' referred to by Lord Lee was, to give one example, the knowledge gained by the Wrights in the development of their aircraft. But Haldane was not interested. In a letter to Lady Jane Taylor[123] (who was, at that time, trying to persuade Haldane about the Wright *Flyer)* he wrote: "The War Office is not disposed to enter into relations at present with any manufacturer of Aeroplanes".[124] Haldane felt the United Kingdom was at a "profound disadvantage compared with the Germans, who were building up the structure of the Air Service on a foundation of science".[125] He considered those with 'successful' designs (i.e., those aircraft which actually flew, or might well do with proper backing) as "only clever empiricists".[126]

And yet David Bloor has noted that in the early years of flight:

> A division of labour quickly established itself. Practical constructors continued with their trial and error methods, while scientists and engineers began to study the nature of the airflow and the relation between the flow and the forces that it would generate.[127]

For Haldane, as he saw it, the piecemeal, cut and try empiricism of the pioneers was not good enough. He wanted a strong scientific basis for British aeronautical work.

[122] Walker, *Early Aviation at Farnborough*, 1: p. 255.
[123] The wife of General Sir Richard Taylor.
[124] Gollin, "Mystery of Lord Haldane," p. 51.
[125] Richard Burdon Haldane, *An Autobiography* (London: Hodder and Stoughton, 1929). p. 232.
[126] Gollin, "Mystery of Lord Haldane," p. 51.
[127] Bloor, *The Enigma of the Aerofoil*: p. 2; ibid.

Indeed, so 'hypnotised by science' was he that in 1908 and again in 1909 he fired two men making great strides in their practical work, J. W. Dunne and Samuel Cody.[128]

There was much debate between 'practically' and 'scientifically' minded men about the early development of British aircraft. Indeed, Cody was sacked for not being properly scientific in his experiments (never mind his results). Dunne had designed an aircraft that was meant to be stable. This was directly at odds with the Wrights' aircraft that required a great deal of effort on the part of the pilot to achieve stability. Haldane ordered tests in the Scottish highlands on Dunne's aircraft and it was unable to achieve sustained flight. Dunne was subsequently dismissed.[129] But Haldane was responsible for establishing important practical and political institutions for further developing British aviation. After sacking Cody he organised the Army Aircraft Factory for the design and development of aircraft, and the Advisory Committee on Aeronautics which was to be headed by Britain's "most distinguished physicist…Lord Rayleigh".[130] By that time, however, many other pioneers such as A. V. Roe, Geoffrey de Havilland, and Samuel Cody were making significant progress in creating a working aircraft. The Wrights did eventually find a buyer in the French Army, selling them a biplane in February 1910.[131]

EARLY AIRCRAFT AND THE INDUSTRY 1909-1914

The inaugural edition of the journal *Flight* in January 1909 took as its starting point the First Paris Aeronautical Salon; indeed, this was the first exhibition of aeronautical technology at all. The article discusses the nature of the aircraft industry at the time:

[128] Cody made the first successful flight in Britain in October 1908.
[129] Bloor, *The Enigma of the Aerofoil*: p. 13.
[130] Edgerton, *England and the Aeroplane*: p. 4.
[131] Jackson, *Army Wings*: p. 16.

> At the present time flight is only just commencing its career as an industry…[and] Although these are the earliest of days, it is impossible to ignore the fact that the flying industry is already born. It is one of those half-hidden aspects of the present situation which makes itself unobtrusively apparent at the Salon, but might have remained unrealised for a much longer period to come had such an occasion not offered an opportunity for bringing it to light. It is a little apt to be forgotten that the more prominently successful experimenters have been at work for a long time…[132]

The article also has some interesting things to say about the monoplanes and biplanes present at the Salon:

> Monoplanes have a distinct superiority in numbers over the biplanes at the first Aeronautical Salon, but presumably it is only a matter of individual preference at the present time as to which of the two types has been adopted. The monoplane has of course less surface that a biplane occupying the same width of spread, and is therefore a higher speed machine. It lends itself to simplicity of construction, and if fitted with a tractor screw[133], as most are, to the use of a direct coupled engine.[134]

Early aircraft manufacture around 1905 to 1908 was characterised by one-off designs usually constructed by very small teams rather than the larger drawing offices of later years. There was general, incremental improvement in performance during these years as illustrated in the following table:

Distance or Time	Place	Aeronaut	Date
Few seconds	*Bagatelle*	*Santos Dumont*	*22 Aug., 1906*

[132] Anon, "The First Paris Aeronautical Salon," *Flight* Vol. 1 No. 1(1909): p. 7.
[133] A 'tractor screw' is a propeller arrangement placed in front of the supporting planes of an airframe instead of behind them so that it exerts a pull instead of a push. Hence, tractor biplane or tractor monoplane. Although this is the most common arrangement for modern propeller driven aircraft, this clearly was not so at the time this article was written. The significance of this being the choice that was still to be made.
[134] Anon, "The First Paris Aeronautical Salon," p. 8.

7-8 meters	*"*	*" "*	*14 Sept., 1906*
50 meters	*"*	*" "*	*24 Oct., 1906*
60 meters	*"*	*" "*	*13 Nov., 1906*
82.6 meters	*"*	*" "*	*" " "*
220 meters	*"*	*" "*	*" " "*
363 meters	*Issy*	*Henry Farman*	*25 Oct., 1907*
403 meters	*"*	*" "*	*" " "*
771 meters	*"*	*" "*	*" " "*
1. 5 kilometers	*"*	*" "*	*13 Jan., 1908*
2. 04 kilometers	*"*	*" "*	*21 Mar., 1908*
2. 5 kilometers	*"*	*Delagrange*	*10 April., 1908*
5 kilometers	*Rome*	*" "*	*27 May, 1908*
9 kilometers	*"*	*" "*	*" " "*

From *Flight*, 2nd January 1909 'Progress of Mechanical Flight', p. 12

The first controlled flight in Britain was an important step in aviation as several European countries, as well as the United States, had already developed successful flying machines. As mentioned above, the Wrights had offered the British War Office their flyer and technical knowledge. Their offer was rejected in large part due to the fact that the Wrights would not demonstrate the flyer until they had a signed contract.[135]

Even before the *Mayfly* disaster in 1910 there was a fledgling or, more accurately, cottage aircraft industry established in Britain by firms such as A. V. Roe, and Short Brothers. For firms such as Vickers two options existed as they considered entering the aircraft industry. They could either design and manufacture a machine from scratch, or they could obtain a license to manufacture a machine designed by

[135] Edgerton, *England and the Aeroplane*: p. 2.

another company. The Admiralty for their part favoured purchasing a manufacturing license. There were two choices that appealed to the Vickers board; the *Sommer Biplane*, or the *Esnault-Pelterie Monoplane* (the *R.E.P*).[136] Eventually a license was purchased for the *R.E.P*. The Admiralty however, were not interested in purchasing any aircraft for Service use.

AERO-ENGINES

Early aero-engines owed much to the development of motor car engines.[137] Many were custom made for their machines; the Wright Flyer for example used a 12 horse-power (h.p.) custom built engine which, incidentally, marked the first use of aluminium in construction of aircraft components. Others adapted motorcycle engines for use in their experimental aircraft. Alliott Verdon Roe used a (rather inadequate and underpowered) 6 h.p. JAP motorcycle engine to power his biplane design in 1907. Finding that he did not have enough power to take off he borrowed a French manufactured Antoinette eight-cylinder 'vee'[138] 24 h.p. engine.

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[136] An interesting aside to the *R.E.P.* is that it is mentioned in the inaugural issue of *Flight* emphasising the hard work done behind-the-scenes. "…it was six years ago that M. Esnault-Pelterie first commenced the work which he has since continued without interruption to the present day…he has built aeroplanes, designed and constructed a very successful engine, and laid down an aviation factory which…is at present probably the largest in existence. And yet he is one of the youngest in the field; in fact, M. Pelterie is a "flying engineer" pure and simple, for he commenced his practical career as soon as he had left his regiment – which he joined directly after taking his degree in science…[his example] so aptly points [to] the moral of "going slow" at first in a new thing. As M. Pelterie himself remarked…"Everywhere to-day I hear the same expressions of surprise and wonder at what is on view, [at the Aeronautical Salon] followed by optimistic conclusions of further wonders to come *immediately*. I am afraid they are going too fast; they forget about our past laborious work"". Anon, "The First Paris Aeronautical Salon."January 2nd 1909, p. 7

[137] Anon, "Engines for Aeroplanes," *Flight* Vol. 1 No. 3(1909): p. 33.

[138] 'Vee' refers to a particular arrangement of cylinders within the engine vertically in a V shape. Other arrangements include 'inline' where the cylinders are in a straight line or a 'flat six' where the cylinders are laid horizontally, facing each other, in banks of three.

By 1908 engine horse-power was climbing towards 50 h.p. and debates were occurring in the aviation press about the best materials and configurations to use in order to achieve maximum power and efficiency. Forged steel vs. cast iron and air vs. water-cooling were just some of the subjects being discussed.[139] At this stage the design, development and manufacture of aero-engines was for the most part being conducted in France. Gnome, Renault, R.E.P, and Antoinette were among the manufacturers displaying goods at the Aeronautical Salon in Paris.[140] This was a cause for some consternation in the British aviation press with *Flight* commenting that:

> It is common knowledge that the United Kingdom has utterly failed to get away well at the start; but all may yet be well if the recognition of that fact is made to act as an immediate stimulant to the British nation…The prospects of the coming season are bright enough for England if only sufficient enthusiasm can be aroused in place of past lethargy…It [British aviation technology] only needs, in fact, more pioneer investigators like Mr. Moore-Brabazon [English aviation pioneer] –who will now, we trust, find sufficient encouragement to keep him at work in *this* country.[141]

These comments offer several important insights into the development of aviation technology in Britain at that time. Firstly, there is the frank admission of the lack of progress in British design and development that (so *Flight* believed) could be remedied by an increased interest in domestic aviation. Secondly, there is the suggestion that some of the more progressive pioneer inventors were being drawn to more enthusiastic locales and indeed *Flight* mention that "…even in France it is two English-speaking men who have so far led the van".[142]

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[139] Anon, "Engines for Aeroplanes," p. 34.
[140] Anon, "Engines for Aeroplanes continued," *Flight* Vol. 1 No. 4(1909): p. 46.
[141] Anon, "The Position of the Aeronautic Industry," *Flight* Vol. 1 No. 2(1909): p. 18.
[142] Ibid.

Having secured sufficient funding Geoffrey de Havilland was able to design and construct his first airframe and aero-engine (the F.E.1) in 1909. It developed 45 h.p. and could achieve 37 miles-per-hour.[143] As promising a development as this was, when de Havilland's F.E. 1 crashed in 1911 it was rebuilt (as the F.E. 2) with a lighter 50 h.p. French Gnome engine. From 1910 the situation was improving somewhat in British aero-engine design as small pioneering firms with little capital and funding were supplemented or supplanted by larger, financially stable companies set up and run by professional businessmen. Bristol Aeroplane Company for example was started in 1910 by Sir Geoffrey White and later became one of the world's foremost producers of aero-engines.

By 1911 some real innovation was taking place in the development of aero-engines. The New Engine (Motor) Company had designed an entirely new two-stroke petrol engine.[144] This was a significant step in aero-engine design. Two-stroke engines fire once every revolution as opposed to the four-stroke engine which fires once every other revolution. This gives the two-stroke engine a significant power advantage. Furthermore, the two-stroke engine does not use valves and so is also significantly lighter than the four-stroke as well as being simpler to construct. In the case of the N.E.C. two-stroke:

> …[It] appears to justify its claim to be the lightest engine in the world for its power; and although it is at the moment difficult to give actual comparative figures it would appear to be an advance upon all others in this respect, mainly due to the difference in the weight of the lubricating oil required by it in comparison with engines of the rotary pattern. It is, at any rate, sincerely to be hoped that this new and extremely interesting flight motor will justify in actual practice all its makers' hopes, for if it does so it will not only put England in a unique and

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143 C. Martin Sharp, *D.H. A History of de Havilland* (Shrewsbury: Airlife, 1982). pp. 34-35.

144 Anon, "The N.E.C. Two-Stroke Flight Engine," *Flight* Vol. 2 No. 52(1910): p. 1052.

> much to be desired pre-eminent position but it will have accomplished something of even wider importance, which is the opening of the door of progress for the two-stroke engine.[145]

The development of a two-stroke aero-engine offered an important potential avenue of development if it could be proved as a reliable and efficient technology and thus as a suitable alternative to the four-stroke aero-engine.

MATERIALS

The first aircraft constructed by pioneers were made of the lightest and most basic materials. The airframe was manufactured of wood obtained from local lumber yards. In the case of Geoffrey de Havilland's first aeroplane white wood "was employed for the longerons and struts…and for the spars and ribs of the wings and the inter-plane struts"[146], piano wire was used for all the bracings due to its strength and a thin cotton cloth was used for covering the surfaces.[147] The undercarriage was constructed of bicycle wheels and bicycle steel tubing.[148] This was in 1908, but by 1909 there were industries devoted to the manufacture of materials for aircraft construction.

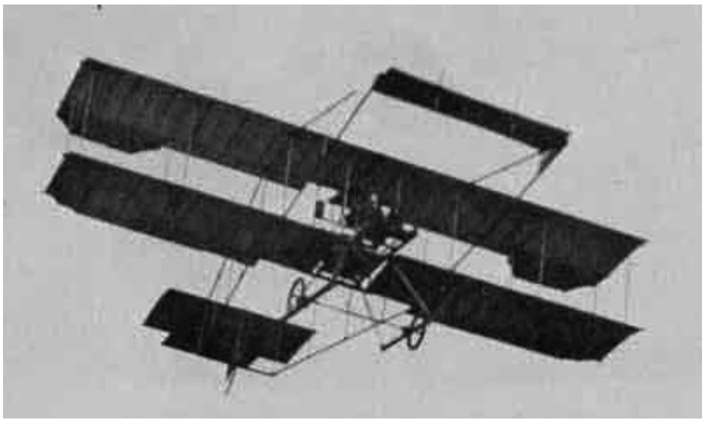

Figure 4 - de Havilland (Royal Balloon Factory F. E. 1), 1910

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[145] Ibid.; ibid.
[146] Sharp, *D.H. A History of de Havilland*: p. 20. Longerson
[147] Longerons, stringers or stiffeners are strips of material to which the skin of the aircraft is attached. Struts are supports between the wings, or as part of the undercarriage.
[148] Sharp, *D.H. A History of de Havilland*.

While wood was the favoured material for airframe construction there were firms engaged in constructing such specialised products as hollow beams, struts and elliptic lattice girders as opposed to the solid beams like as those used by de Havilland.

The type of materials didn't change very much over the course of the First World War and typical British military aircraft were made with a wooden structure covered in a treated fabric. Likewise, in Germany most Service aircraft were constructed using these materials, however, German aircraft manufacturers were also much more willing to experiment with metal construction in both the structure and skin of their aircraft with many successful examples appearing throughout the war. A short discussion on the relative benefits or drawbacks of metal and wood should be useful here.

THE FIRST WORLD WAR AND INFLUENCE ON AIRCRAFT DESIGN

In 1910 Colonel J. E. B. Seely[149] reported to a group of aviation pioneers that "…[the Government] does not consider that aeroplanes are of any possible use for war purposes".[150] The widespread use of aircraft as military machines had not occurred to the Admiralty and War Office much before 1911. By April of that year Britain had just six military aeroplanes in contrast to the French War Department which had 208.[151] It was the growing prospect of war in Europe that made the British government more enthusiastic about military aviation and as a result, many orders for military machines were placed. By the start of the First World War in 1914 "the Naval Wing of the [Royal Flying Corps] had a total of ninety-three heavier-than-air

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[149] British politician, Secretary of State for War (1912-1914), and despite his protestations to the contrary in 1910, the development of a Flying Corps was of special interest to him.
[150] Peter Fearon, "The Formative Years of the British Aircraft Industry, 1913-1924," *Business History Review* 43, no. 4 (1969): p. 479.
[151] Ibid.

craft [including airships] and the Military Wing, 179".[152] All of which were unarmed and used solely for reconnaissance.

Initially, military aircraft were used primarily as reconnaissance tools for spotting troops and the fall of artillery as well as taking aerial photographs of battlefields. Pilots began taking pistols and rifles up with them to take pot-shots at enemy reconnaissance aircraft. 'Fighter' aircraft developed as a response to these reconnaissance machines and a desire to stop the enemy from gathering intelligence from the air. In conventional terms a 'fighter' aircraft was a machine that was able to carry a pilot, machine gun and gunner with the purpose of shooting down enemy aircraft. One crucial piece of technology which really furthered the use of military aircraft as fighters was the 'interrupter gear' which allowed a forward facing machine gun mounted in front of the pilot to fire through the propellers without hitting them.

Tactically, the interrupter gear provided the German Luftstreitkräfte (Imperial German Army Air Service) with an enormous advantage over the Royal Flying Corps when it appeared. Previously, the advantage had been held by the Vickers *Gun Bus* (F.B. 5). This was a pusher[153] biplane with the propeller mounted behind the pilot which allowed for a pilot operated forward facing machine gun. The *Gun Bus* was "the only definitely offensive aeroplane then in existence".[154]

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[152] Ibid.
[153] The pusher design contrasts with the tractor design of aircraft mentioned above whereby the propeller and engine is arranged behind the pilot producing a push rather than pull effect and giving an unobstructed forward view. It was therefore ideal for mounting a machine gun.
[154] Anon, "Milestones - The Vickers Machines," *Flight* Vol. XI No. 24(1919): p. 760.

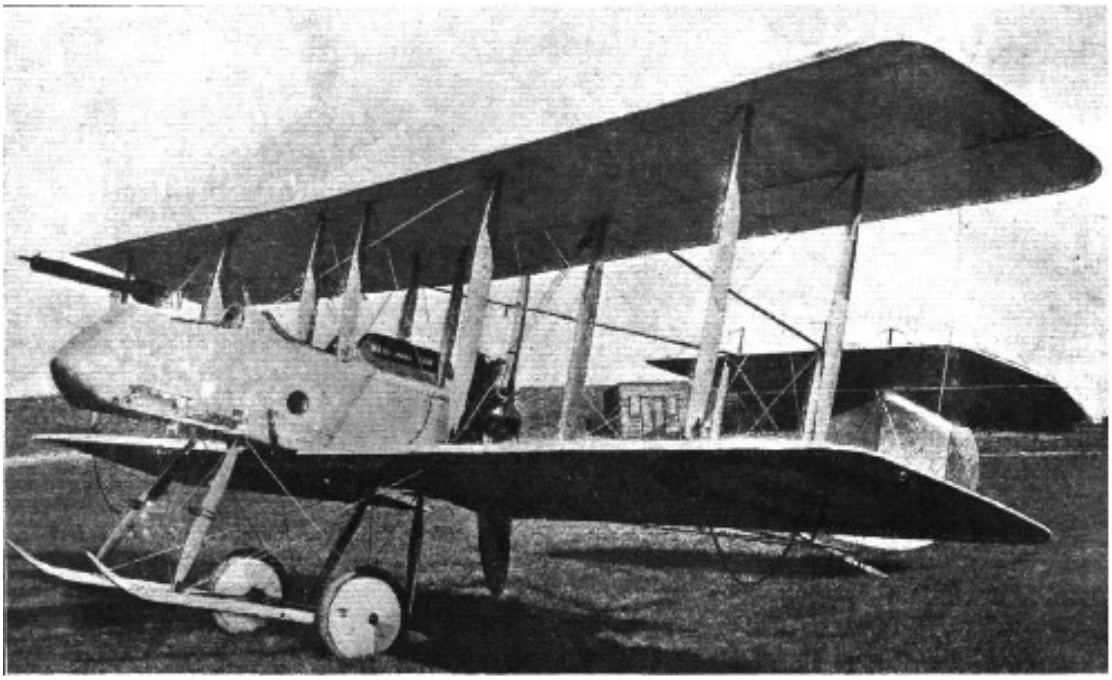

Figure 5 – Vickers F. B. 5 *Gun Bus*[155]

The *Gun Bus* held a decisive advantage over the Luftstreitkräfte for around eight months until the arrival of the new Fokker aircraft using the new interrupter gear swung the balance back in Germany's favour. The Fokker interrupter design had the trigger mechanism of the machine gun enabled and the interrupter mechanism would disable it when the propellers were in the way. By contrast the first British synchronization gear had the trigger mechanism normally disabled and would enable it to fire when the propeller was clear. The effect of the German mechanism before the R.F.C. could bring in its own had a devastating effect on the morale of British pilots which prompted the frantic rush to develop a similar mechanism.[156]

155 Ibid. Note the position of the propeller at the rear of the pilot and the forward facing machine gun allowing for a wide offensive firing arch.
156 Scott, *Vickers*: p. 121.

STABILITY AND CONTROL

Early British aircraft largely followed the same developmental process as the Wright brothers in America and Henri Farman in France, for example. The inductive trial and error process served the early pioneers well. However, as interest in the potential military use for aircraft increased and following a number of accidents, the Advisory Committee for Aeronautics became keen to adopt a strict set of testing procedures before any commitments were made to purchase any aircraft for Service use.

Testing covered two main areas: (i) strength, stability, and reliability of components, and (ii) performance.[157] Initially, particular attention was paid to the development of testing procedures relating to the strength and stability of the airframe and the reliability of the engine. It was found by the ACA committee investigating accidents that while the majority of such incidents were caused by engine failure, stronger airframes and airframe components would give the pilot a better chance of landing the aircraft when such problems arose.

In a report to the Secretary of State for War, the Accidents Committee, made up chiefly of members from the Advisory Committee for Aeronautics (ACA), recommended that:

> …with every machine purchased, stress diagrams or calculations should be required, which should be carefully checked. They [the Committee] would suggest that the Advisory Committee for Aeronautics be asked to report on the best method of carrying out these calculations.[158]

This was the beginning of a systematic and standardised approach to testing. The ACA wanted a comprehensive system of tests devised to be applicable to any machine under consideration for adoption by the military. Furthermore, in addition to

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[157] Speed, range, rate-of-climb, degree of control and so on.
[158] NA AIR 1/2100/207/28/12 – Report of the Departmental Committee on the Accidents to Monoplanes, 1912, p. 8

tests measuring strength and stability, a set of tests was also devised to measure performance. These tests had the ultimate purpose of deciding the suitability of a machine for adoption, and also for deciding between machines under consideration.

There was a great desire to achieve the most accurate results possible, and to that end the formulation of testing procedure and the design of instruments used for testing were continually developed to achieve greater accuracy.

The Advisory Committee for Aeronautics was in large part responsible for recommending additions to the equipment at the National Physical Laboratory. Beginning in 1910 the ACA was to recommend several upgrades to testing equipment at the NPL in their yearly report. The ACA reports covered many different aspects of testing relating to aircraft and the range of work undertaken was very wide. The NPL was tasked with determining such diverse things as the strength and elasticity of fabric and metal, obtaining greater efficiency of propellers, as well as work on aero-engines, aerodynamics and so on.

In 1920 the ACA produced a report titled 'Summary of the Present State of Knowledge with Regard to Stability and Control'.[159]

> The present analytical method of investigating the stability of an aeroplane has been developed from the analysis of Professor G. H. Bryan. The problem considered by Bryan is the behaviour of the aeroplane after it has suffered a slight disturbance from the conditions of equilibrium, and it is important to remember this limitation, since theoretical results deduced by this method will not necessarily correspond to the behaviour of the aeroplane for larger disturbances.[160]

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[159] NA AIR 1/2100/207/28/11 – Summary of the Present State of Knowledge with Regards to Stability and Control, December 1920.
[160] Ibid. p. 2

The report noted that "The theoretical aspects of the problem of stability are…well developed, but further work is required to correlate theory and practice". At that time, the Air Ministry considered that the main lines of progress open were:

1. to obtain the values of the stability derivatives due to the wings from model tests and to develop satisfactory formulae for predicting these values from their geometrical properties.
2. to obtain the stability derivatives due to the airscrew, and also the effect of the airscrew on the derivatives due to the slipstream.
3. to compare the observed and predicted behaviour of aeroplanes.

Certainly, one of the most important methods of appraising the stability and control of an aircraft was observation and the experiences of the pilots flying the aircraft. Testing of the Armstrong-Whitworth reconnaissance machine, powered by a 150 h.p. Lorraine-Dietrich engine found the following:

1. Stability
   a. Longitudinal — Good.
   b. Lateral — Good.
   c. Directional — Would be good if trimmed correctly.
2. Controllability
   a. Longitudinal — Good.
   b. Lateral — Very heavy.
   c. Directional — Very heavy, on one side.
   d. Taxiing — Very Good.[161]

Therefore, based on the observation and experiences of the pilot it was reported that although stability in the air was good, controllability was 'heavy', making the machine "very tiring" to fly.[162] It is important to realise that whatever the predictions about how an aircraft might fly when built, ultimately it was the pilots who gave the ultimate appraisal of the aircraft's performance.

[161] NA AIR 1/716/27/19/26 – Reports on Trials of Various Aircraft, March 1917 – Feb 1919, 150 h.p. Armstrong Whitworth Reconnaissance Machine p. 10
[162] Ibid.

In striking contrast to the Armstrong Whitworth reconnaissance machine, the Vickers *F.B.14 A* reconnaissance machine, powered by the same Lorraine-Dietrich 150 h.p. engine, was found to have poor stability and control:

1. Stability
   a. Longitudinal — Good.
   b. Lateral — Fair, but slow.
   c. Directional — Fair.
2. Controllability
   a. Longitudinal — Fair.
   b. Lateral — Very bad.
   c. Directional — Fair.[163]

Over 100 *F.B. 14*s were built, despite its poor stability and control that made it tiring to fly. It seems from the test reports that the Air Ministry were more concerned with speed and altitude at the time rather than control and handling characteristics which is not unreasonable when considering a reconnaissance aircraft. Indeed, the machine powered by the Lorraine-Dietrich engine was a one-off as the 160 h.p. Beardmore engine that was used in the production *F.B. 14*s was notoriously unreliable, with 50 machines delivered to squadrons without engines fitted.

By 1920, however, the Aerodynamics Sub-Committee of the ARC agreed "that the problems of control and stability should take precedence over those of performance".[164]

The opinions of test pilots were highly important for further refinement of the aircraft after its first flight. After the first flight of the Supermarine *Spitfire* in 1936, chief test pilot Mutt Summers declared: "I don't want anything touched". Fellow Supermarine test pilot Jeffrey Quill noted that:

> This was destined to become a widely misinterpreted remark. What he meant was that there were no snags which required correction or adjustment before he flew the aircraft again.

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[163] Ibid. Vickers Reconnaissance F.B. 14 A, p. 10
[164] NA DSIR 23/1525 – ARC Scheme of Research, 1920-1921, p. 3

> Mutt's comment has crept into folklore as implying that the aeroplane was perfect in every respect from the moment of its first flight – an obviously absurd and impracticable notion. *After one 15-minute sortie the aircraft could not be other than still largely untested and unproven*.[165]

First flights were an important part of the development process of all aircraft, and it was based upon these initial observations by the test pilot, communicated to the engineers and designers, that the first modifications could be made. Aircraft prototypes designed for the military were sent to the Royal Aeronautical Establishment at Martlesham Heath for further trials and testing. The RAE reported to the Air Ministry and usually their recommendations proved decisive.

In the case of the *Spitfire,* initial testing at the RAE focused entirely on performance figures and gave no information on the handling characteristics of the aircraft. This kind of focus shows that at the time the Air Ministry was only interested in the aircraft's performance. As the tests on the *Spitfire* were being carried out at the RAE, the Hawker *Hurricane*, six months ahead of the *Spitfire* in development, was showing a similar top speed and performance to the *Spitfire*. This meant that should the Supermarine aircraft not demonstrate a substantial increase in speed over the *Hurricane* then an order would not be placed.

RESEARCH AND DEVELOPMENT

In 1922 the Royal Aeronautical Society (RAeS) wrote an article for the journal *Flight* reviewing the importance of aeronautical research in Britain and describing British aeronautical activity.

> Four bodies represent British Aeronautical activity, and these bodies respect each other's domains and are connected by agreements and joint committees; they are:-

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[165] Quill, *Spitfire - A Test Pilot's Story*: p. 85.

(a) The Royal Aero Club, concerned with the control of races, competitions and touring, the international sporting and touring rules and triptyques.[166] (b) The Air League of the British Empire, concerned with propaganda, mainly in the interest of aerial defence. (c) The Royal Aeronautical Society, whose province is the spread of the study of aeronautical technics, both in theory and practice, including those branches of physics, chemistry, etc., which relate to the aeronautics – as well as scientific research and publications therewith. This Society is officially represented on the Aeronautical Research Committee of the Air Council. (d) The Society of British Aircraft Constructors, the organised body of British aircraft constructional firms. The technical staff of the last are, in significant numbers, members of the Royal Aeronautical Society.[167]

The RAeS considered applied scientific research in the same article and summed up the general state of British scientific research:

> Applied scientific research has in England, for one reason or another, suffered from serious and increasing disabilities since the earliest flight. These disabilities arose from many causes, but notably from the fact that, though research has forced itself into public recognition as fundamental to any technical advancement, when it comes to the detailed allocation of time and work this recognition becomes blurred by reason of other factors, technical, administrative and financial, which tend to obscure its fundamental importance and crowd it out of existence.

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[166] Permits for motor vehicles.

[167] Anon, 'The Importance of Research in Aeronautics', *Flight*, January 26th, 1922, p. 55

CHAPTER TWO: THE 'LEAN YEARS', 1918-1924

The years immediately following the First World War of 1914-1918 were difficult for both the newly anointed Royal Air Force (RAF), which came into existence on the 1st April 1918, and the fledgling British aircraft industry. The so-called 'Lean Years' of 1919-1924 followed a period of intense investment in aeronautical technology, of changing doctrine and strategy within the Royal Flying Corps (the predecessor to the RAF) and of the organisation of aircraft production on a mass scale. Some historians have derided the development of aeronautical technology in this period, scarcely looking beyond the low aircraft production figures in these years. This is apparently enough to paint the now familiar picture of managerial incompetence, a backwards looking Air Ministry and technologists uninterested in pushing developmental limits with respect to aircraft (for instance, a reluctance to push for the monoplane) and component design (delayed adoption and work on the retractable undercarriage for example).[168]

However, the 'Lean Years' produced some of the most forward thinking developments in aeronautical technology. Perhaps the most notable of these, and the main focus of this chapter, was the change from wood to metal in the construction of military aircraft. Research and development was scaled back but there was a greater prioritisation of items for research, changing from a system where anything that promised success was looked into, to one where those items offering the greatest chance for results were given priority.

This chapter looks at the aircraft industry as it came out of the First World War and examines how it dealt with a radically reduced market for not only military but also civilian aircraft. It will also discuss the changing ways in which research and

[168] Fearon, "Formative Years of the British Aircraft Industry." Fearon, "The British Airframe Industry and the State." Postan, *British War Production*. See also, Barnett, *Audit of War*: pp. 127-8.

development (R&D) was conducted, the ways in which the doctrine and strategy formulated by the RAF affected the design of aircraft and it will tell the first part of the story of the change from the use of wood to metal in the structure of the airframe.

The end of the First World War brought with it a sharp contraction in the market for aircraft and the very real danger that the autonomous air service, the Royal Air Force (RAF), would be shut down. Edgerton discusses the massive growth experienced by the British aircraft industry throughout the war in his *England and the Aeroplane*, and the figures are startling:

> The war saw the creation of a very large aircraft industry, with increases in output accelerating through the war. Monthly output increased from about 10 per month at the beginning of the war to 122 in 1917 and 2688 in 1918. The labour force employed making aircraft engines and parts, but excluding materials, rose from nearly 49,000 in October 1916 to 154,000 in November 1917 to 268,000 in October 1918.[169]

The end of hostilities in 1918 left £165m in outstanding contracts for aeronautical material in Britain, and left the RAF in possession of around 22,600 airframes and 38,500 aero-engines.[170] This enormous surplus and drastically reduced operational role for the RAF meant that demand for aircraft was extremely low in the years immediately following the War and firms were, for the most part, engaged in reconditioning surplus aircraft for Service use rather than designing their own machines and spending money on research and development programmes.

That is not to say that research and development did not continue, however, and the research establishments at the National Physical Laboratory (NPL) based at Teddington and Royal Aeronautical Establishment (RAE) at Farnborough sustained effort in research and development throughout the 'lean years' which was,

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[169] Edgerton, *England and the Aeroplane*: p. 14.
[170] NA AIR 2/1322 – Aircraft Supply Committee Report, 1931, p. 35.

unsurprisingly, heavily prioritised due to extensive funding cuts. For the most part, the NPL was concerned with the aerodynamic qualities of airframes and the testing of materials. From an NPL publication on its history:

> One of the NPL's earliest areas of research after its foundation was in the magnitude and distribution of wind forces on structures such as bridges and roofs. In 1908 these techniques were brought to the study of flight leading to rapid advances in the efficiency and safety of the aeroplane…[171]

The NPL constructed a wind tunnel and began testing materials. By 1920 the properties of engineering materials that could be tested included: "strength, elasticity, ductility, hardness, abrasion resistance, fatigue resistance and impact resistance".[172] As to the practical work with aeronautical technology undertaken by the NPL, Patrick Hassell has noted that:

> The story of Mitchell's…*[S.4], S.5, S.6,* and *S.6b* [the Supermarine Schneider Trophy entries] and their engine development has been told many times, but with too little emphasis on the many hours of wind-tunnel testing at NPL, which whittled away at the profile drag of these machines so that, for example, the fuselage of the *S.5* had 29 per cent less drag than that of the near-perfect *looking S. 4*.[173]

By contrast the RAE was responsible for testing the performance of aircraft components such as engines, airframes, propellers, landing gears or anything else specific that could be submitted for performance testing, as well as overall aircraft under consideration for Service use. However, before getting into the demarcation of research and development work it is worth describing the position of aviation in Britain at the end of the First World War.

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[171] Anon., *N.P.L. History Highlights* (The National Physical Laboratory2008). p. 4; ibid.
[172] Ibid., p. 5.
[173] Patrick Hassell, "Advances in Aerodynamics," in *Biplane to Monoplane - Aircraft Development, 1919-1939*, ed. Phillip Jarrett (London: Putnam, 1997), p. 144.

The establishment of the Air Ministry and RAF in the early months of 1918 brought with them at least a temporary end to the "bitter inter-service exchanges over reform proposals, spiced with political manoeuvring and acrimonious public debate. When hostilities ceased, however, the muted groundswell of discontent heightened and many of the old arguments against an independent air ministry and separate air force once more found favour".[174] There was a period of uncertainty concerning the future of the RAF as an independent air force and for a time it appeared as if the air services would once again be divided between the Army and Navy.

Chief of the Air Staff Lord Trenchard

When Prime Minister Lloyd-George offered Winston Churchill a choice between the Admiralty or War Office in 1919 he is reported by Churchill to have said: 'You can take the Air with you in either case; I am not going to keep it as a separate department'.[175] As Sweetman notes, "this was precisely the fear of [Independent] Air

[174] John Sweetman, "Crucial Months for Survival: The Royal Air Force, 1918-1919," *Journal of Contemporary History* 19, no. 3 (1984): p. 529; ibid.
[175] Ibid., p. 530.

Force protagonists; for if the Air Ministry were lost, the independent air force must soon follow into oblivion".[176] Chief of the Air Staff Lord Trenchard and Churchill went to work on re-inventing the RAF as a service while reducing its size.[177] It was crucial that they be able to present the air force as an economic alternative to the other forces used for Imperial defence, and that the reorganisation of the RAF be brought in on (or preferably under) budget:

> It should be added that the financial provision which the cabinet have approved as governing the scale of the Royal Air Force during the next few years is approx. 15 million pounds per annum. It is upon this basis that this scheme [the organisation of the RAF] has been prepared, and it is upon his basis that it is hoped the Estimates of next year will…be framed.[178]

Thus, while Trenchard set about defining new operational roles for the Royal Air Force, he reduced its size from roughly 200 squadrons and 150,000 officers and men in 1918, to 79,570 in 1919-1920, and to 29,730 in 1920-1921.[179] One example of the savings that could be made from using air power in the colonies is that of Somaliland:

> Trenchard…suggested to Churchill that the RAF be given the opportunity to subdue a festering uprising in Somaliland. Churchill agreed. The results were dramatic: Somaliland was pacified at a cost of only £77,000, rather than the £6,000,000 it would have cost for the two army divisions originally planned.[180]

Secretary of State for Air during the 1920s, Sir Samuel Hoare originated the phrase 'control without occupation'. This was the primary goal of the RAF during the 1920s, to enable control of a region of the Empire without the need for a permanent garrison. In addition to policing Somaliland, the RAF was also responsible for maintaining

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[176] Ibid.
[177] Ibid. See also, Malcolm Smith, "The Royal Air Force, Air Power and British Foreign Policy, 1932-1937," *Journal of Contemporary History* 12, no. 1 (1977). Phillip S. Meilinger, "Trenchard and "Morale Bombing": The Evolution of Royal Air Force Doctrine before World War Two," *The Journal of Military History* 60(1996).
[178] NA AIR 1/17/15/1/84 – Trenchard's Memo on the Formation of the Permanent Organisation of the RAF, with note by Sec. of State for Air, 11th December, 1919, p. 2
[179] Anon., "Editorial Comment," *Flight* XX, no. 14 (1928): p. 224.
[180] Meilinger, "Trenchard and "Morale Bombing"," p. 253.

control of Iraq saving untold sums of taxpayer money and ensuring its survival at the same time.[181]

This early success gave Trenchard valuable breathing space, allowing the demand for the use of air power in the Empire to grow. The example of Somaliland was especially powerful given the dramatic reduction in defence spending following the end of the First World War. Had the RAF been split between the Admiralty and the War Office, the responsibility for training and funding of an air force would have been spread between the two. However, as Trenchard and Churchill were able to demonstrate the need for an independent air force, so long as it remained cost effective it could stay.

In understanding Air Staff thinking throughout the early-mid 1920s with regard to aircraft development and procurement we must consider the circumstances surrounding the RAF and the aircraft industry immediately following the War. The Aircraft Supply Committee report of 1931 gives a good account of some of the problems of design after 1918. Bearing in mind the massive surplus left over from the First World War, the report hints at the origins of early design stagnation:

> …the strength of the Royal Air Force, in the immediate post war years was subject more than once to reductions as the result of Government decisions, and these naturally caused a further redundancy of material. During this intensive period of pruning and selection the aircraft industry, consisting of those firms which had manufactured aircraft during the war and had decided to continue if possible in peace, was kept alive mainly on the repair and reconditioning of war types of aircraft and engines.[182]

Furthermore, Britain was operating under the so-called ‘ten year rule’, which

[181] David Omissi, *Air Power and Colonial Control - The Royal Air Force, 1919-1939* (Manchester: Manchester University Press, 1990). pp. 8-16, 18-37.
[182] NA AIR 2/1322 – Aircraft Supply Committee Report, 1931, pp. 35-36

supposed that Britain would not be involved in a major war for at least ten years.[183] The result was that while there was a general incremental progression in military aircraft R&D, there was ultimately no need for widespread, heavily funded development into new types of aircraft for the RAF. Indeed, the 'ten year rule' originated as a basis for the formulation of defence spending thus radically curtailing funding to the RAF and aeronautical research.

Despite the efforts of the Air Ministry to keep firms alive following the end of the War many firms did go out of business while others merged to create many of the firms best known throughout the inter-war years and the Second World War.

> The Sopwith Aviation Co. was liquidated and reformed as Hawker Engineers; A. V. Roe was taken over by Crossley Engineering to make car bodies, but also continued to make aircraft. Sometimes firms were lost but design teams were kept together. Airco, the largest wartime producer, was taken over by the small-arms, motor-cycle and car (Daimler) firm BSA for its plant, but it spawned two independent aircraft firms, de Havilland and Gloucester Aircraft. The Handley Page company tried car assembly and lost a lot of money…The Bristol Company, under strong Air Ministry pressure, took over a highly successful engine design team led by Roy Fedden…Bristol engines were very successful in the 1920s and 1930s: not only were many exported but foreign firms acquired licences (including the mighty French company Gnome-Rhone) which brought in tens of millions of pounds. By 1930 Bristol provided 'the principal engine of nearly half the world's airline and more than half the air forces'. Of the many firms which made and designed aero-engines during the war, only two others stayed on as a significant force in the industry: Rolls-Royce and Napier.[184]

The pressure placed on the aircraft industry due to the reduced market for aircraft was

[183] Peter Silverman, "The Ten Year Rule," *Royal United Service Institution* 116(1971). Ken Booth, "The Ten-Year Rule: An Unfinished Debate," *Royal United Service Institution* 116(1971). Stephen Roskill, "The Ten Year Rule - The Historical Facts," *Royal United Service Institution* 117, no. 1 (1972).

[184] Edgerton, *England and the Aeroplane*: pp. 22-24.

acute and in 1919 the Civil Aerial Transport Committee[185] asserted that an aircraft manufacturing industry was essential for the national defence and that the government must necessarily play an important role in aeronautical development.[186] The proposed solution to this problem was the creation of a small ring of preferred manufacturers that would receive preferential treatment from the government. For instance, in times of hardship orders would be taken from larger, more affluent firms and subcontracted to the less fortunate, struggling ones, thus keeping a small hub of firms operational at all times.[187]

There were several important consequences of this system. Firstly, with the government as paymaster it had very nearly absolute control over the firms within the ring. This control was exercised in a number of ways but by far the most effective was to threaten ejection from the ring to any firm who, for whatever reason, refused to tow the Ministry line and accept recommendations from the Air Staff. The system had the further effect of heavily influencing aircraft design as the Air Ministry were simply able to feed firms the type of work they were keen to specialise in.[188]

While this system did keep the industry alive during the 'lean years', it was limited, primarily by the funding available to the Air Ministry for the procurement of new aircraft at that time.[189] Furthermore, it had the undesirable effect of producing too many different types of aircraft, and the short production runs that were characteristic

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[185] NA AIR 1/702/27/3/736 – Reports of the Civil Aerial Transport Committee (1918). The Committee was formed to report to the Air Board with regard to a range of aeronautical matters following the War, such as: development and regulation of civil and commercial aviation; technical and practical questions as to the possibilities of performance of aircraft; business questions relating to the position of the aircraft manufacturing industry; problems of scientific research and education of expert designers, engineers and pilots and so on.
[186] Fearon, "The British Airframe Industry and the State," p. 236.
[187] Ibid., p. 243.
[188] Ibid.
[189] Postan, *British War Production*: Table 1, p. 2.

of this period made the aircraft that were produced more expensive. For instance, Zeitlin notes that by 1931 the RAF were using 44 different airframes and 35 types of aero-engine.[190] Nevertheless, at a time when aircraft procurement was very low, and the danger of a firm going out of business was very high, the Air Ministry was able to provide enough business for the industry with the long-term goal of keeping it strong enough to expand when needed.

The focus of Declinist historians has mainly been centred on the firms that went out of business or struggled during the years after the war.[191] There were, however, several highly successful firms within the industry that were not reliant on Air Ministry support/control and thus had autonomy regarding the design of their aircraft. For instance, although de Havilland was a member of the ring they produced no military aircraft for the RAF between 1920 and 1941, concentrating instead on civil aircraft, and by 1938 had constructed 43% of all civil aircraft registered in Britain.[192] Furthermore, Supermarine were highly successful in the production of flying boats for civilian use as well as for the RAF.

Sir Robert McLean of Vickers and Supermarine perhaps best described the Air Ministry ring system when he said:

> The position of Supermarine is typical of all aviation businesses…they rely upon designing acceptable new types for the Air Ministry and when they succeed the profits are very large; when they fail it is still the policy of the Air Ministry to keep them alive.[193]

During the amendment of RAF procurement policy during 1924 the Air Member for

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[190] Jonathan Zeitlin, "Flexibility and Mass Production at War: Aircraft Manufacture in Britain, the United States, and Germany, 1939-1945," *Technology and Culture* 36, no. 1 (1995): p. 51.
[191] Fearon, "Growth of Aviation in Britain.", Fearon, "The British Airframe Industry and the State.", Barnett, *Audit of War*.
[192] Robin Higham, "Government, Companies, and National Defence: British Aeronautical Experiment, 1918-1945 as the Basis for a Broad Hypothesis " *The Business History Review* 39, no. 3 (1965): p. 326.
[193] Ritchie, *Industry and Air Power*: p. 14.

Supply and Research (AMSR) commented that:

> In selecting firms without examining their design, I have assumed that the 18 firms now in the SBAC [Society of British Aircraft Constructors] have advanced sufficiently under Air Ministry tutelage to be relied upon to produce good work…[194]

The implication here is that by 1924 the Air Ministry could reasonably expect the industry to do what it was told. The control exercised by the Ministry in terms of allocating work, specifically the type of aircraft to be built and the fact that many firms relied upon Air Ministry favour to survive ensured this to a great extent.

The charge levied against the Air Ministry by the industry's representative body the SBAC was that such strict specifications laid out by the Ministry was having a bad effect on design:

> The present position in aircraft design in this country has, in the Society's opinion, been brought about by rather too much restriction on design and equipment and to changes which the designer is called upon to make in the course of construction.[195]

However, all of this disagreement over design specification detracts from one of the most interesting and technically progressive movements in British aircraft design, that of the change from wood to metal in the construction of airframes, which for the most part occurred during the so-called lean years.

THE WOOD TO METAL SHIFT (I), 1919-1925

Of the changes in aircraft design and construction that took place during the 1920s and 1930s certainly one of the most significant was the move from the use of wood to metal in the structure of aircraft. The change took place in different countries at

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[194] NA AIR 20/68 – Aircraft Development Programme – AMSR Memorandum, 28th November 1924.
[195] NA AIR 20/68 - Aircraft Development Programme – Charles Allen (SBAC Secretary) to the Air Ministry, 7th February 1925

different times, and in Britain the use of metal for the construction of aircraft was considered by several manufacturers throughout the years before a large-scale change was made. The widespread adoption of metal was not a purely technical choice, by which I mean it was not simply obvious that metal was superior to wood and therefore adopted without question. In Britain the pace of change was governed to a large extent by the government, specifically the Air Ministry, and its relationship with the aircraft industry.

Therefore, in order to adequately explain how and why the change took place when it did, we must ask several questions. In the first instance we need to understand how wood became the first choice material for constructing aircraft, effectively eliminating the initial widespread use of metal in the process. We need to understand the factors that led to the popularization of metal as the next most important step and then how this belief in the superiority of metal spread to and throughout Britain. Finally, we need to understand how this change was directed and managed by the Air Ministry and industry.

This section will argue that the change from wood to metal was made possible by virtue of a number of inter-linked factors, and was not merely the choice of Air Ministry officials or the industry. Metal construction of the airframe was possible from the earliest days of flight and so it was not a case of the process having to be invented when the change in Britain took place, but rather it had to be refined and adopted by a community of manufacturers as well as the government.

Wood or Metal? The Initial Choice, 1909-1918

The first question to be addressed is how wood came to be the most commonly used material in the construction of aeroplanes. Many of the pioneers used the Wright brothers *Flyer* as the starting point for their first successful machines after numerous unsuccessful attempts.[196] This was particularly the case in France, where the Wright's demonstrated and sold their machine. Captain Ferdinand Ferber wrote:

> Just think of it, that without this man (Wilbur Wright) I would be nothing (je ne serais rien); for I would not have dared, in 1902, to trust myself to a flimsy fabric if I had not known – from his account and from his photographs – that it would bear me. Think of it, that without him, my experiments would not have taken place…I would not have had [Gabriel] Voisin[197] as a pupil; the backers such as [Ernest] Archdeacon and Deutsch de la Merthe would not – in 1904 – have offered the prizes you know about; the press would not have sown the good seed everywhere; your journal…would not have quadrupled its circulation; and other specialised journals would not have been born.[198]

Drawing on the work of Sir George Cayley, Otto Lilienthal, Octave Chanute and others, and bringing their own originality to the process, pioneers like the Wrights, Ferber, Farman, Verdon-Roe and de Havilland were able to make their first flights in home-made aircraft. Thus, like the Wright brothers before them, Ferber *et. al.* very much stood on the shoulders of these aeronautical giants.

Initially, around 1909, the prevailing belief amongst this fraternity was that wood was lighter than metal for the same strength, though far more bulky.[199] Indeed, by 1909 there were at least two firms who specialised in the manufacture of hollow beams and struts made from wood for the purpose of manufacturing aircraft.[200]

Thus, the very first aircraft to achieve 'powered, sustained and controlled flight' in Britain were made from wood. 16th October 1908 marked the first successful light in Britain, undertaken by Samuel Cody in the *British Army Aeroplane No. 1* at

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[196] Gibbs-Smith, *The Rebirth of European Aviation*: p. 128.
[197] Another successful pioneer (1880-1973).
[198] Gibbs-Smith, *The Rebirth of European Aviation*: p. 36.
[199] Anon, "The First Paris Aeronautical Salon," p. 8.
[200] Ibid.

Farnborough.[201] 1908 also saw the entry into the world of aviation of another British pioneer, Geoffrey deHavilland, whose first aircraft was made from timber purchased from a lumber yard in Fulham, simply “asking which was the lightest wood obtainable”.[202] The material of choice was American whitewood, chosen by de Havilland because of his belief that such a choice would obtain a straight grain. However, having crashed his first attempt after some 35 feet of flight, the fractured wood displayed an internal softness which was not immediately obvious. Upon starting construction on his second machine, essentially designed to the same specifications but also to be stronger, he chose silver spruce, ash and hickory.[203] In a 1909 article on ‘The Building of a Flyer’, *Flight* suggests that:

> So far as the material is concerned, we may assume that wood is to be employed for the entire framework, and the question at once arises as to what wood is the best. If a reference book on the subject of timber be consulted, it will be found that a certain number of trees produce timber which is both light and strong, but it is not alone sufficient to have mere figures of this sort; practical knowledge of timber and the peculiarities of different kinds is essential for success. For instance, Short Brothers, who are building the Wright flyers in England, use nothing but spruce, while the Voisin machines are constructed of ash. Now spruce is a wood which is lighter and stronger than ash, but, as a rule, is a timber blemished by a number of knots. To obtain a sound spruce spar of 15 feet in length is a matter of considerable difficulty.[204]

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[201] Gibbs-Smith, *The Rebirth of European Aviation*: pp. 135-35, 238-39, 55. Gibbs-Smith, *Aviation - An Historical Survey*: p. 136. Philip Jarrett, "October 16, 1908 - Britain's First Powered Flight," *Aeroplane* November(2008). Richard Gardner and David Wilson, "Making it Real," *Aeroplane* November(2008).
[202] Sharp, *D.H. A History of de Havilland*: p. 20.
[203] Anon, "Another All-British Biplane - Details of the de Havilland Machine," *Flight* II, no. 67 (1910): p. 266.
[204] Anon., "The Building of a Flyer," *Flight* 1, no. 23 (1909): p. 332.

Metal is not even mentioned as a possibility, and as we will see, despite the early successes of Hugo Junkers in Germany in 1914-15, the belief in Britain that metal was 'impracticably heavy' persisted well into the 1920s.

Hugo Junkers, the First World War and Early British Interest in Metal

The first commercially and operationally viable all-metal aircraft were pioneered in Germany by Hugo Junkers during the First World War.[205] It has been suggested that German pioneering of metal construction stemmed from a reduced industrial capacity and a subsequent need for some kind of technical edge.[206] Addressing the Royal Aeronautical Society in 1923 Junkers explained his pursuit of metal aircraft as the answer to most, if not all, of the major technical problems with wooden aircraft.[207]

Junkers first successful machine was the *J. 1* of 1915. In his 1923 lecture (before metal construction was adopted in a widespread fashion in Britain) he noted that:

> Among the advantages [of metal construction] the first is the greater durability. Wood is subject to the dangers of fire and decay, and splinters when breaking; it bursts and warps from the effect of humidity and change of temperature and the glued joints split; finally it is attacked by insects. No wooden aeroplane, serviceable for any length of time in the Tropics, has been produced as yet. Metal is free from all such drawbacks.[208]

It is worth noting that Junkers was first and foremost a businessman, metal construction being his particular métier and, therefore, he had a vested interest in extolling the virtues of metal to the great and good of the British aircraft industry.

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205 Gibbs-Smith, *Aviation - An Historical Survey*: p. 179. Hugo Junkers, "Metal Aeroplane Construction," *The Journal of the Royal Aeronautical Society* Vol. XXVII(1923). Schatzberg, *Wings of Wood, Wings of Metal*: pp. 23-26.

206 Schatzberg, *Wings of Wood, Wings of Metal*: p. 22; ibid.

207 Junkers, "Metal Aeroplane Construction," p. 417.

208 Ibid.

Nevertheless, his aircraft were successful, though in terms of performance no more so than machines made of wood.

Junkers concern that wood was susceptible to the influence of heat and humidity, which thus made continuous "re-setting" of the aeroplane necessary, has a particular resonance for the British with its Empire spanning regions in which such conditions were common. Robert Brooke-Popham, Director of Research at the Air Ministry[209] had already investigated the question of 'Aeroplanes in Tropical Climes' in 1921.[210] Furthermore, Junkers noted that, "a constancy of form is necessarily important in aeroplane wings, slight changes frequently producing a distinct deterioration of the aerodynamic qualities".[211]

Junkers spent a great deal of time developing his all-metal machines during the First World War. The *J. 1, J. 2 and J. 4* were all entirely metal machines (metal fuselage and skin), they were possessed of fully-cantilever (unsupported by external bracing such as struts and wires) wings and were built for the German air force in number. The *J. 1* (1915) was initially viewed with some suspicion on the part of the German authorities because it was felt the machine was "impractically heavy".[212] Although the *J. 1* was able to produce a relatively good top-speed of 105 miles-per-hour, the authorities were unconvinced. Junkers was able to press on, however, and the improved *J. 2* made an appearance in 1917. Also appearing that year was the *J. 4*

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[209] Robert Brooke-Popham, or 'Brookham', was a significant figure in inter-war aviation. He served as a combat pilot in the First World War, became the Director of Research at the Air Ministry between 1919-1921 and established the RAF staff college at Andover. During the 1920s and 1930s he worked with the Air Ministry in a variety of roles, compiling reports and contributing to discussions on aircraft development and research. He is perhaps more famously associated with the Fall of Singapore in 1942.
[210] Robert Brooke-Popham, "Aeroplanes in Tropical Climates," *The Journal of the Royal Aeronautical Society* Vol. XXV, no. No. 131 (1921).
[211] Junkers, "Metal Aeroplane Construction," p. 417.
[212] Gibbs-Smith, *Aviation - An Historical Survey*: p. 179.

which was markedly different from his previous machines, built largely from the aluminium alloy duralumin. The *J. 4* was the first all-metal aircraft built in large numbers, making use of mass production manufacturing processes.

The progression of Junkers aircraft during the First World War allows him to be fairly credited with "the design and construction of (a) the first practical cantilever wing aeroplanes, (b) the first practical all-metal aeroplanes, and (c) the first practical low-wing monoplanes, all of which he continued to develop successfully over the years".[213] This expertise developed during the First World War also made Junkers an expert in methods of metal construction, and of course organisations such as the RAeS were keen to hear from him about his processes and design. However, Junkers was not the only advocate of metal construction. In Britain there was a growing trend towards metal, chiefly born from Britain's own 'experts', or those who had persevered with metal construction where others had not.

The points put forward by Junkers in his lecture were the same arguments in favour of metal put forward by several people in Britain shortly after the First World War.[214] But while Junkers advocated the use of metal for both resistance to the elements and the aerodynamic benefits that could be achieved through greater structural stability, British thinking was more concerned with the fact that "metal aeroplanes will stand adverse climatical [sic] conditions, long storage and…the wear and tear of every-day use in temperate climates better than aeroplanes largely built of timber and joined with glue…".[215]

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[213] Ibid.
[214] John D. North, "The Case for Metal Construction," *The Journal of the Royal Aeronautical Society* Vol. XXVII(1923). Originally: John D. North, "The Case for Metal Construction," *Flight* XIV, no. 722 (1922). A. P. Thurston, "Metal Construction of Aircraft," *Flight* Vol. XI No. 21(1919).
[215] North, "The Case for Metal Construction."

Eric Schatzberg has argued that the change from wood to metal in American aircraft construction came about through a change in public perception and a symbolic relationship between the use of metals and ideas of technical progress.[216] In Britain, however, early flirtations with metal construction were driven by far more practical considerations. A shortage of timber was one such reason for British experimentation with metal but for the most part continued construction in wood was cheaper that changing to metal during the war. Change during the war would also have involved a vast purchase of new plant and machinery involving great cost and a lot of time.

British warplanes did not suffer for their construction materials. The R.F.C. fighters entering service in 1917 were capable of performance equal to that of their German opponents. The Junkers *D.1* aircraft was manufactured from metal and offered no significant advantage, in terms of performance, over the British *S.E. 5*. Both could achieve speeds of around 120 miles-per-hour and reach altitudes of over 19,000 ft. But perhaps the largest benefit from the use of metal construction (in terms of manufacturing) was the ability to mechanically guarantee the quality of the materials. Indeed:

> The advantages of metal were obvious. It could be checked scientifically, it was more homogeneous than wood, it was better for large scale production, and its life was longer. Wood could not be cut as accurately as metal, consequently wooden aeroplanes, even though built to the same design, could differ considerably in weight and performance. However, the cost of designing and preparing drawings for a British military machine of metal construction in 1925 could well exceed the whole cost of building a similar machine of wood.[217]

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[216] Schatzberg, "Ideology and Technical Choice." Schatzberg, *Wings of Wood, Wings of Metal*.

[217] Fearon, "Formative Years of the British Aircraft Industry," p. 486. *Note*: I suspect that Fearon is suggesting that the advantages of metal were obvious to the aviation community.

In 1918 the Air Ministry commissioned a report on the Junkers *D.1*. The report was written by Robert Brooke-Popham and much of the language is helpful to understanding Air Ministry and RAF thinking on metal machines by the end of the First World War:

> It may be mentioned…that the machine had been dumped in the open and had shared the varied weather of several months with other machines constructed of wood and fabric materials. The Junker had hardly suffered, while the orthodox type of machine [i.e. that which was used in Britain] had seriously deteriorated.[218]

Thus, British, or more accurately Air Staff, interest was more concerned with the longevity which could be achieved by metal machines rather than any particular belief in the superior strength or aerodynamic benefit of metal. Reports and comparisons made between metal and more conventional machines of wood, such as those from John Dudley North[219] or Junkers went a long way towards suggesting the potential benefits of metal to wider audiences such as the RAeS.

That being said, initially the technical community and aviation press had far more interest in the potential for metal aircraft design than the Air Staff. As A.P. Thurston[220] who was chief assistant and designer to Sir Hiram Maxim from 1903, and during the First World War he was a technical inspector for the Royal Flying Corps, noted:

> The War has been fought with machines made of wood, a most unsatisfactory material from a constructional point of view. Wood warps and cracks; is unsuitable for tropical climates; splinters easily in a crash; is liable to transfix the aviators; is non-homogeneous; uncertain in strength and weight; weakens rapidly when exposed to moisture, and is not produced in any quantity in this country.

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[218] NA AIR 10/494 – Report on the Junker All-Metal Monoplane Type D. 1, July 1919, by Robert Brooke-Popham

[219] Chief Designer at Boulton-Paul Aircraft

[220] Air Crash investigator during the First World War and Assitant Engineer to Sir Hiram Maxim

> On the other hand metal does not splinter; it is much safer in a crash, the members hanging together and forming a shield to protect the aviators; its properties are known to a fine degree and may be relied upon; it can be produced in immense quantities, and, moreover, metal members, after breaking, can still carry a considerable load.[221]

Thurston's belief was that is would take ten years (from 1919) before metal construction would reach the stage of development that it would have done in ten months under war conditions.[222] He further argued that the advantages of metal construction "are not confined to greater strength, lightness, reliability and ultimate cheapness. Its use will enable many new developments to be made in the actual design of aircraft [such as variable camber wings or load bearing skins]".[223] The object of Thurston's paper was to do more than outline why metal was a preferable material. It was intended to call for and encourage Government support for the continued development of metal machines.

CREATING A CONSENSUS: DEVELOPING METAL AS A CHOICE

The change from machines made of wood to those of metal required something of a consensus within the aviation community. An amount of momentum was needed to prove the case for metal construction to the Air Staff who were, at that time, in a position of almost total control over the military aircraft industry. The aeronautical press was instrumental in putting out the message for those advocates of metal construction. J. D. North's paper 'The Case for Metal Construction', mentioned above, was printed in both the Journal of the Royal Aeronautical Society and *Flight*. It represented one of the early scientific efforts to persuade the aeronautical community of the virtues of metal construction. In fact, North was not the first to do

[221] Thurston, "Metal Construction of Aircraft," p. 680.
[222] Ibid.
[223] Ibid.

so, his paper joined a growing number of voices inside the industry and community who favoured a switch to metal.

The first serious treatment of the wood-metal question in the United Kingdom was a paper given in 1919 by Dr. A. P. Thurston. In this role he was able to replace many of the rule-of-thumb methods for measuring structural failures through the application of scientific procedure. His paper 'Metal Construction of Aircraft' laid down many of the ideas picked up by North in 1922, and he hoped that "by drawing public attention to the problem, and placing information at the disposal of firms interested, [they could] hasten the development of this important industry".[224] Thurston lamented the fact that of the one thousand or so metal machines that had been used with success in the allied air services, "not one had been made in [Britain]". He further believed that the future of Britain as a nation and its place in the world depended to a very great extent upon its position in the air – "we cannot afford to neglect so important a subject".[225]

Thurston's experience with structural failures made him uniquely familiar with the shortcomings of wooden construction (as noted above) and it was his belief that the vital members of aircraft structures could be, and were at the time, made lighter and stronger in metal than in wood. One of the most striking points that he makes about the shortcomings of wood is on the variation in the strength and weight of spars of the same type of wood from the same type of machine. He notes that: "Spars for one type of machine were found to vary in weight from 6 ½ lb. to 16 lb., and the strength varied in practically the same proportion".[226] He also noted that:

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[224] Ibid., p. 680.
[225] Ibid.
[226] Ibid.

The strength decreases with the amount of moisture absorbed. Thus, the strength of spruce in compression decreases 230 lb. per sq. in. per 1 per cent. of moisture between 10 per cent. and 25 per cent. moisture.[227]

This was a crucial part of the argument in favour of metal for an Air Force tasked with policing a vast empire, and this fact was actually more important to the Air Staff than might be supposed as one of the major rationales for the continuation of the Royal Air Force following the First World War was the fact that it could police the Empire at a fraction of the cost of a standing army (see Somaliland example above). This meant sending aircraft to hot and humid locations and for Thurston:

Wooden machines sand tested under the very favourable conditions of a dry workshop…showed a much greater strength than in the field. A sodden machine in the tropics may have only half the strength of the same machine when tested in the workshop at home. Moreover, owing to the disposition of wood to warp or split, particularly under tropical conditions, a wooden machine quickly gets out of truth and requires trueing up.[228]

He also believed in the potential for the further development of aircraft components utilising metal, such as variable camber wings which would allow for a lower landing speed.

Thurston and North were not the only ones advocating, to greater or lesser extents, the virtues of metal construction. In Brooke-Pophams' report to the Air Ministry mentioned above describing the major design characteristics of a Junkers *D. 1* metal monoplane, the main benefit was its reaction to poor weather and storage conditions, not the the fact that it was a metal monoplane fighter. Therefore, British interest in metal construction initially arose from a belief, proven empirically by machines developed and used abroad, that metal would last longer and was more durable to the effects of the elements.

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227 Ibid.
228 Ibid.

Three years later in 1921, John North gave his paper to the RAeS. At the time of writing the article, North was the Chief Engineer and Designer for Boulton & Paul Ltd. and had by that time devoted a lot of his attention towards all-metal machines. The essence of his paper was to suggest that metal aircraft would be lighter for the same strength as wood because so much more wood is needed to achieve the same strength as metal. The example he gives is convincing:

> …with a power loading [pounds of weight per horse power] of 15 [lb per h.p.], which is representative of most modern commercial aeroplanes, a reduction of structure weight from 34 per cent. to 26 per cent. increases the revenue load [useful load] from 34 per cent. to 43 per cent., an increase of nearly 25 per cent. in the utility of the aeroplane. In the case of the high performance aeroplane, the increase will be seen to be vastly greater, and in many cases makes possible a type of aeroplane which will be placed out of court with the heavier structure weight. I have every reason to believe that the structure weight of aircraft can be reduced from an average of 33 per cent. to an average of 25 per cent. to 27 per cent. by the use of metal construction, an advantage which…is absolutely imperative in the case of military machines.[229]

North considered that it would not be possible to achieve this reduction in weight straight away and he was not offering a "process of design", but he based his belief on both "theoretical considerations and practical experience". Indeed, he had actually made an aircraft from metal for Air Ministry approval. The *Bolton* was a metal biplane developed as a photographic and reconnaissance machine. One prototype was built under contract and flew in November 1922 but was not adopted for service use.

There are no official records detailing the machine and one can only assume that either it did not fly well or the metal construction put off Air Ministry officials

[229] North, "The Case for Metal Construction," p. 632-33. For the sake of clarity, North is referring to reducing the average structure weight of an aircraft from 33% to between 25%-27% through the use of metal.

who believed there was a lack of aircrews skilled in working with metal machines.[230] It is, however, very interesting to note that the *Bolton* is referred to as being all-metal or all-steel in certain publications.[231] It was a steel airframe covered in doped fabric, thus it was really still a hybrid of the old school (doped fabric covering) and new (all-steel framework). It was believed that the extra weight involved in covering the wings with metal "would outweigh any advantage arising out of metal covering".[232]

This belief illustrates two important facts; firstly, that metal skin had not yet been developed as a part of the load bearing structure of aircraft; and secondly, that power-to-weight ratio's had not yet become favourable enough to justify the increase in weight required to adopt a metal skin. Still, North's experiences of metal construction gave him hope that with "experiment on broad lines…unhampered by the necessity of obtaining immediate results from experimental expenditure…" structure weights could be reduced by adopting metal at "no very distant date".[233] However, North had a major problem with the way in which structural members of aircraft were designed and is worth quoting at length:

> Firstly, the conditions of flight for which the aeroplane is to be designed. These are fixed by an Order in Council, and are interpreted by a series of good round numbers delivered after much labour by a committee. Over the manner of arriving at these numbers a decent veil is cast which it would be unwise to disturb. But the Committee seems to know its job in so far as the aircraft are not abnormally heavy, nor do they collapse in the air. These numbers are converted to external forces in a particular manner founded on precedent supported by very doubtful aerodynamic data and also fortified by the same Order in Council. The loads in the members are then estimated by ignoring those members to take account of whose presence

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[230] See the *Springbok* example below.
[231] K. J. Meekcoms and E. B. Morgan, *The British Aircraft Specifications File, 1920-1949* (Tonbridge: Air Britain, 1994). p. 35.
[232] Anon., "The Boulton and Paul "Bolton" (P. 15)," *Flight* XIV, no. 40 (1922): p. 571.
[233] North, "The Case for Metal Construction," p. 633.

would seriously complicate the calculations and by making what are often the wildest assumptions as to the nature of the joints between the members.[234]

North was thus concerned not just about this apparently inaccurate method of determining the loads operating on structural members and how strong they should be, but also about the process of design by committee. This process was a result of the top-down approach to aircraft design and procurement which characterised the post-war years whereby decisions made at the top regarding the desired characteristics of an aircraft heavily determined what designers could and could not do. In essence, such figuring of coditions set the boundaries within which a designer could work. This type of design by committee was a major feature of aircraft procurement throughout the 1920s and well into the 1930s. Despite this, North conceded that the:

> …whole process works after a fashion because aeroplanes are not designed by science, but by art in spite of some pretence and humbug to the contrary. I do not mean to suggest…that engineering can do without science – on the contrary, it stands on scientific foundations – but there is a big gap between scientific research and the engineering product which has to be bridged by the art of the designer.[235]

The first advocates of metal construction were 'experts', people who had had constant exposure to aircraft with structural failures such as Robert Brooke-Popham and A. P. Thurston, or those designers who simply believed that aircraft of metal would be superior to those of wood such as J. D North and of course Hugo Junkers. Eric Schatzberg has argued that:

> The technical arguments advanced by…advocates [of metal] were fairly uniform, whether published in Germany, France, Great Britain, or the United States. These arguments claimed a multitude of advantages for metal in fire safety, weight efficiency, manufacturing costs and

[234] Ibid., pp. 650-51.
[235] Ibid.

> durability. Yet in each of these four areas, practical experience with metal aeroplanes in the 1920s failed to confirm metal's purported superiority.[236]

Whether or not this was in fact the case in Britain is actually not as important as the question of how convincing these arguments were, and to what extent they informed and shaped the decisions that were eventually to be made by the Air Staff. There is no doubt that certain claims made by the early advocates of metal in Britain were not provable. 'Proof' could only be ascertained through the experience and testing of working examples. Certainly, there was a great deal of emphasis on what was 'expected to be achieved' through research and development. This is what Constant called a 'presumptive anomaly', the idea that in the future the conventional and accepted form would be found wanting or that, as in this case, a different paradigm would do a better job.

However, Thurston and North, for example, clearly state that their intention is to grow the industry through debate, suggestion, and the transfer of information. Furthermore, it was not just those who wrote for the aeronautical press who were in favour of such a change. In replies to Henry Tizard in 1920: A. J. Sutton-Pippard; Major F. M. Green; F. S. Barnwell; J. D. Siddeley and The Royal Aircraft Establishment were all in favour of the use of metal in the structure of the airframe, to greater or lesser extents.[237] None of what might be termed 'technical specialists' – those who were intimately involved in the design and construction of airframes – argued against the adoption of metal, nor suggested that a change over to metal would not happen.

[236] Schatzberg, *Wings of Wood, Wings of Metal*: p. 45.
[237] NA DSIR 23/1558 – Letters on Future Design of Aircraft, 1920, Replies to Sir Henry Tizard.

It is hard to accept Schatzberg's claim that "practical experience with metal aeroplanes in the 1920s failed to confirm metal's purported superiority". Indeed, exposure to the Junkers machines had gone a long way to proving the longevity of metal over wood. Those named above, North, Siddeley, Green and the rest, were aware of the limited research that showed the *potential* for further development along similar lines; that metal could provide the same strength as wood but weigh less.

The Air Ministry and the Metal Question

The reasons behind the beginnings of interest in metal construction in Britain are one thing, but it still leaves the most important question of how such a widespread change took place. How did the interest and belief of a few pioneers become the standard for the military aviation industry by the early 1930s?

During the First World War a shortage of timber led to the use of steel tubing in the manufacture of aircraft fuselages, and while the practical results were "meagre"[238] experimentation continued after the War:

> Owing to the shortage of many essential materials, large numbers of aircraft in War service had been built of materials which would not have been accepted for such purposes had other conditions prevailed. Thus, although the Royal Air Force at the close of the war had thousands of aircraft of many types, all were not suitable for Service use in peace. The Supply of silver spruce and other special timbers of which aircraft had been mainly constructed, was always a difficulty during the war; and towards the end, *steel tubing made its appearance, for use in the construction of fuselages notably in the Vicker's twin-engined bomber.* Experiments in the manufacture of planes without the use of timber were also initiated by certain pioneer firms. The practical results achieved from metal planes during the war, however, were meagre *and for various reasons this type of construction was not developed or adopted*.[239]

[238] NA AIR 2/1322 – Aircraft Supply Committee Report, 1931, Appendix IV 'Review of the Problems of the Design and Supply of Aircraft since the Great War', p. 35
[239] Ibid.

The problem for the designers of the industry and the Air Ministry was a fundamental lack of orders for new machines.[240]

As mentioned above, the ring system put in place by the Air Ministry after the First World War put the government in control of military aircraft design and construction. The consequence of this control for the change from wood to metal in military aircraft was that the Air Staff had almost complete control in governing the pace of change. They were concerned not just with the actual timescale of the shift, but they also had a hand in directing the more technical aspects of it. The technical specifications laid down for aircraft to be designed for the Service often specified the parts of the aircraft which were to be designed with metal and those to be designed with wood.[241]

As mentioned above, one of the major arguments in favour of replacing wood with metal in aircraft construction was the resistance of metal to tropical climates and bad weather more generally. However, in the 1919-1924 period there was much debate within the aircraft industry and Royal Air Force about just how big an advantage metal would give over wood. Robert Brooke-Popham spent just over a month in Egypt and Mesopotamia (modern day Iraq) investigating the problems faced by aircraft in tropical climates.[242]

He considered that, broadly, the main troubles facing aircraft were focused on timber shrinkage, punctured tires, inadequate shock absorbers, petrol supply and hangers/aerodromes. His assessment of the use of wood in tropical climates is of most interest to us here, however, and he noted that:

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240 Ibid.
241 See Sinnott, *The R.A.F. and Aircraft Design*: pp. 24-28. Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*: p. 40.
242 Brooke-Popham, "Aeroplanes in Tropical Climates."

With regard to timber shrinkage [in Egypt], I feel that this is a nuisance but not a danger. It is, of course, due to the humidity in the East being different to what it is in England. Timber undoubtedly does shrink when it arrives in Egypt or at Bagdad [sic], but in the former case a definite limit is reached in about two months, after which no further shrinkage occurs, and once the necessary adjustments are made to allow for this, no further difficulties are experienced from this cause.

There must also be a definite limit to the amount of shrinkage in Mesopotamia, otherwise one would have the finest conjuring trick on record, but I have no definite figures as to when this limit is reached.

Certainly in Egypt there is no sign that the timber swells again in the cold weather. As regards Mesopotamia, all I can say is that I could get no evidence to show that any reswelling occurs. So long as a machine has to fly merely in Egypt and Mesopotamia there is no necessity to make them all metal, but I still believe that when machines fly constantly from London to Bombay and back it will be necessary to do away with wood in their structure.[243]

Frederick Handley-Page, in the discussion which followed Brooke-Pophams's paper referred to his experience of metal aircraft in the United States Postal Service:

He was not altogether convinced that their [metal machines] would come very quickly. When one had wood, spare parts could easily be carried or made on the spot, and wood had so much greater local strength than steel. If one had steel an enormous supply of spare parts must be carried to repair the wings with the special kind of material that was necessary for aircraft. So he was not altogether convinced yet that they had completely done away with wood for these big tropical temperatures…When he [Handley-Page] was over in the States this year he examined metal machines which had been in operation under service conditions on the postal service. There was first of all trouble with the petrol tanks leaking. The petrol tanks being in the planes were blown off with the inevitable explosion that occurred after an engine back-fire. They had also had trouble with the metal covering of the planes corroding and being eaten away by electrolyte action, especially where those parts were heavily stressed. That

[243] Ibid., pp. 564-66.

> simple little trouble seemed to be a considerable one from the point of view of keeping the machines in condition for flying.[244]

It seems highly likely that Handley-Page is referring to the Junkers *F13* (named the *JL-6* in the United States), eight of which were purchased for the U.S. Air Mail in 1920 for $200,000 and had serious problems with its fuel system. Within weeks four of the eight machines originally purchased had burst into flames while in flight and the Post Office sold the remaining four for $6,044.[245]

At around the same time in 1920, the first truly all-metal aircraft designed and built in Britain appeared, the Short *Silver Streak.* The major distinction between the *Silver Streak* and other machines claiming to be all-metal is that the Short Bros. aircraft was made with a metal structure and metal skin, as distinct from the usual metal framework (or metal and wood hybrid) and fabric skin.[246] It was an experimental machine, but one was purchased by the Air Ministry for testing and a further machine, the *Springbok*, was developed but neither saw service with the RAF and machines of this type of construction were not seen again in Britain for some time after.[247] The *Springbok* was developed under specification 19/21 as:

> [A] replacement for the Bristol fighter in use in the Middle East, requiring an all-metal structure to avoid the problems created [by] the high humidity of the region…Trials were completed satisfactorily but defects in the wing skin…led to its replacement with doped fabric. Due to rudder blanketing, the Springbok proved susceptible to spinning, [one of the prototypes] was lost in such a manner. It has been suggested that the Springbok did not go into production as a type for the RAF due, in part, to the lack of RAF maintenance personnel familiar with metal structures and stressed skin repair.[248]

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244 Ibid., p. 577.
245 Schatzberg, *Wings of Wood, Wings of Metal*: pp. 40-45.
246 Anon, "Air Ministry Acquire Short "Silver Streak"," *Flight* XIII, no. 8 (1921).
247 Gibbs-Smith, *Aviation - An Historical Survey*: p. 183.
248 Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*: p. 45.

Of particular interest in the case of the *Springbok* is the delay from the issue of the specification in 1921, to the prototype's first flight in April 1923. The so-called 'Geddes Axe' reduced national defence spending from £189.5m in 1921-22 to £111m in 1922-23.[249] The plans for the *Springbok* were shelved at the publication of the Geddes reports (December 1921-February 1922) and eventually re-instated at the end of 1922.[250]

The Aircraft Supply Committee (ASC) of 1931 commented that:

> After the war experiments were continued, but owing primarily to the lack of orders resulting from the large surplus of existing machines very little progress was made for the first few years beyond further development of the manufacture of planes from steel strip.[251]

Arguments in favour of a wide-spread shift to the use of metal in the construction of aircraft do much to highlight the arguments against such a change. As suggested in the ASC report above, a lack of orders for new aircraft in the years immediately after the First World War did not allow for widespread experimentation into the use of metal in the main structural members of an airframe, let alone research into all-metal machines requiring a metal covering. The prevailing belief at the time was noted by A.J. Sutton Pippard in 1920 in reply to a request for information from Sir Henry Tizard:

> [On the 'Materials used in design'] The present structure composed partly of timber and partly of steel is, I feel convinced, bound to disappear very soon. The earliest form of structural work in civil engineering practice was of course stone or wood. When metals became available the first use to which they were put was to re-inforce [sic.] the beam, but the flitched beam is now

[249] Henry Higgs, "The Geddes Report and the Budget," *The Economic Journal* 32, no. 126 (1922). Andrew McDonald, "The Geddes Committee and the Formulation of Public Expenditure Policy, 1921-1922," *The Historical Journal* 32, no. 3 (1989).
[250] Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*: p. 45.
[251] NA AIR 2/1322 – Aircraft Supply Committee Report (1931) – Appendix IV 'A Brief Review of the Problems of the Design and Supply of Aircraft Since the Great War', p. 35. My italics.

> practically extinct and the great majority of structural work is of course done in steel. The disadvantages of composite structures are obvious and where there is such a low margin of safety as in the aeroplane I think it is certain they cannot survive. I think then that concentration should be made upon metal construction. It is difficult to say whether steel or a light alloy will be the ultimate material. At present I am strongly in favour of steel but the discovery of a suitable light alloy would of course modify design very appreciably.
>
> Another material which I feel will disappear is fabric. Durability will be one of the essential features for commercial success and fabric is not an ideal material from that standpoint. I imagine therefore that considerable importance attaches to the discovery of a suitable metal covering for wings, *which in my opinion should form part of the structure for actual load carrying and not be a covering merely.*[252]

This view was shared by John North in 1923:

> All the history of engineering relates the gradual displacement of timber by lighter and more durable structures of steel, but such a transition in aeroplanes [it is felt by the engineers and constructors] is difficult, if not impossible, to realise with advantage.[253]

As an advocate of metal construction North was referring to others within the community who felt metal aircraft would be too heavy. Nevertheless, movements were made towards utilising metal more frequently within the airframe. One of the first had its origins in a First World War fighter, the Siddeley-Deasy *S.R. 2 Siskin* of 1918. This particular aircraft was powered by an ABC[254] *Dragonfly* radial engine which was, as it became immediately obvious to those involved, highly unreliable, prone to overheating and severe vibration. Also, there was a large disparity between the power promised (320 h.p.) and the power which was delivered (270 h.p.).[255]

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[252] NA DSIR 23/1558 – Letters on Future Design of Aircraft, 1920 – Replies to Sir Henry Tizard. Reply from A. J. Sutton Pippard, 10th November 1920, pp. 8-9. My italics.
[253] North, "The Case for Metal Construction," p. 3.
[254] **A**ll **B**ritish (Engine) **C**ompany.
[255] Bill Gunston, *World Encyclopedia of Aero Engines* (London1986).

Despite this glaring shortcoming, enough flight time was had to allow an assessment of the handling and manoeuvrability characteristics of the airframe which, it was deemed, were excellent. A new engine was added, the Siddeley *Jaguar*, which achieved much better results and the newly dubbed *Siskin II* made its first flight on 20th March 1921. A specification was issued by the Air Ministry in 1922 for a single-seat, high performance landplane (14/22). This specification was essentially a directive for the newly formed Armstrong-Whitworth company to develop the *Siskin II* into a military machine. As well as fitting it with a new engine as mentioned above, the designer Major F. M. Green decided to redesign the *Siskin II* with a composite wood and metal structure, retaining the fabric skin of the previous models, and it was issued as the *Siskin III*.[256] The composite method was much favoured by aircraft designers:

> The aeroplane engineer, designer, constructor or user, not unnaturally, is inclined to pin his faith to the system of composite construction, which, brought to a state of high perfection, he has found to serve him well in the past.[257]

The *Siskin* was a great success. Around 500 were built and the aircraft itself was in service for more than a decade. It took part in races like the Kings Cup due to its excellent aerobatic qualities.

THE RESEARCH ESTABLISHMENTS: ACA, ARC, RAE & NPL

The Advisory Committee for Aeronautics (ACA) was created on the 30th April 1909, its mandate was to examine and give order to questions of aeronautical research, and also to advise the Government on aeronautical research. At its inception several of the most eminent physicists, mathematicians, and engineers were members of the

[256] Owen Thetford, *Aircraft of the Royal Air Force since 1918* (London: Putnam, 1971). pp. 20-24. Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*: p. 51.
[257] North, "The Case for Metal Construction," p. 632.

Committee. The ACA was founded by Lord Haldane while he was Secretary of State for War; its first President was Lord Rayleigh, and its first Chairman, Sir Richard Glazebrook, who was Director of the National Physical Laboratory (NPL) at the time. The main function of the ACA was to "address technical problems presented to them by the Admiralty and War Office".[258] Thus, the problems encountered by the Admiralty and War Office in the construction of aircraft and airships would be analysed and passed to the NPL or Royal Aircraft Factory (later the Royal Aeronautical Establishment) for experiments and tests, the results of which were passed back to the Admiralty and War Office through the ACA in the form of Reports and Memoranda.[259] An early priority for the Committee, and one that would remain central to British aeronautical research throughout the inter-war period was stability. In 1919, the ACA was renamed the Aeronautical Research Committee (ARC). They performed the same function, but reported to the newly formed Air Ministry.

In the years immediately following the First World War (1919-1923) the defence budget was slashed and funding for research and development (R&D) in aviation technology was cut back. Edgerton has argued that by the mid-1920s research and development in aeronautics was stronger, or certainly better funded, than at any point previously:

> In the interwar years it was stronger than before the war, and perhaps stronger than during the war itself. The RAF and the Air Ministry prided themselves on their support of research and technological development. In the 1920s and early 1930s the Air Ministry's R&D spending represented more than 20% of total expenditure on aircraft and equipment. The Air Ministry was easily the largest R&D spending institution in Britain. In the mid-1920s it was spending £1.34m on R&D, compared with £0.98m by the Admiralty, and £0.49m by the War Office.[260]

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[258] Bloor, *The Enigma of the Aerofoil*: p. 14.
[259] Ibid., pp. 14-15.
[260] Edgerton, *England and the Aeroplane*: p. 35.

In 1920, Professor Leonard Bairstow of the ARC wrote a memo outlining how work should be divided between the Air Ministry and the Research Council . He suggested that:

> ….some broad line of demarcation should be recognised between the work of the Aeronautical Research Committee and that of the Air Ministry. To the former it would be appropriate to allot research and non-routine test work and to the latter the routine test work.[261]

He went on to argue that:

> A general investigation of the lateral control or stability of aircraft would originate with the ARC whilst the testing of [more specific] Avro type ailerons on F boats would arise at the Air Ministry. Further, it is suggested that the routine or specialised type of test should, as far as possible be carried out at establishments under direct Air Ministry control.[262]

Bairstow alludes to early problems in the programme of R&D for the research establishments under the Air Ministry and ARC in the same memo:

> The programme of the RAE…contains 126 items. That of the NPL…48-50. A return from the RAE shows that to meet these requests (in addition to Air Ministry tests not reported to the ARC) there is a scientific and technical staff of 60-70 whilst the NPL probably accounts for a rather smaller number. The number of items in the programme appears to be too diffuse for adequate advance against difficulties. *There will be a tendency to change effort to easier problems rather than run the danger of an apparent slow rate of progress…*[263]

The ARC for their part "agreed to adopt generally the recommendations contained in the [Prof. Bairstow's] paper without accepting quite so rigid a distinction as that drawn…" and also that "…it may not infrequently be necessary to proceed with a less

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261 NA DSIR 23/1510 – ARC Programme of Work, 1920, Prof. Bairstow's Memo, July 1920, pp. 1-2
262 Ibid.
263 Ibid. p. 3. Emphasis added.

urgent research because the means of progressing with the more urgent is for the moment wanting".[264]

The ARC was split into six sub-committees', each with a designated sphere of interest.[265] In 1920, the most pressing R&D concerns were the improvement of the stability and control of aircraft, and, "…to develop a reliable engine suitable for Civil Aviation". In materials, the concentration was focused on structural materials for the wings, rivets, and the fatigue properties of steels.[266] The simple fact was, of course, that the direction research took was heavily prioritised, but it was governed more by a realistic sense of what could be achieved than simply budgetary or bureaucratic concerns. That being said, there were some financial problems for the NPL in particular following the short-lived, post-war economic boom. From 1921 until 1924 their expenditure fell before rising again in 1925.[267] Certainly, by 1925 the Air Ministry was faring better (in terms of budget share) than others for scientific research funding:

Air Ministry………………….. £1,373,000
Admiralty…………………….. £983,000
War Office…………………... £495,000
DSIR…………………………. £380,000

Ministry of Agriculture…….... *£348,000*[268]

[264] NA DSIR 23/1525 – ARC Scheme of Research, 1920-1921, October 1920, pp. 1-3
[265] Ibid. p. 1. 1. Aerodynamics; 2. Engines; 3. Materials and Chemistry; 4. Meteorology; Navigation and Atmospheric Electricity; 5. Fire Prevention; 6. Accidents.
[266] Ibid. p. 6
[267] Russell Moseley, "Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years," *Notes and Records of the Royal Society* 35, no. 2 (1980): p. 175.
[268] R. MacLeod and K. Andrews, "The Committee of Civil Research - Scientific Advice for Economic Development, 1925-1930," *Minerva* 7(1969): p. 699. Reproduced in: David Edgerton, *Science, Technology, and the British Industrial 'Decline'* (Cambridge: Cambridge University Press, 1996). p. 38.

In 1925, the Air Ministry's research money was still dealing with flying characteristics, stability, and airflow. Furthermore, there was "…urgent need for better information on the characteristics of biplanes with unequal wings, an arrangement now widely used by designers".[269] For the engine sub-committee development of a sleeve-valve engine was paramount, "The practical results already obtained with stratified charges (the type of 'charge' within the cylinder of the engine) are promising enough to warrant much further investigation".[270]

The ARC had an interesting and difficult relationship with the industry's representatives to government, the SBAC. For the 1926 programme of research at a joint meeting the SBAC suggested four additional items of research.[271] The ARC was not convinced that SBAC proposals should be the focus of ARC, NPL or RAE research but would be suitable enough for SBAC firms to 'pool' the research themselves. Interestingly, the proposed experiments on monoplane wing positions show a good deal of foresight from the SBAC, and a willingness to move development forward. While the ARC thought this was a good idea, their immediate reaction was to have the firms do it themselves.[272]

The work directed by the Air Ministry and ARC, and carried out by the NPL and RAE was not the only source of aeronautical technology development. The air races and world record flights, largely undertaken privately by the aircraft firms

[269] NA DSIR 23/1987 – ARC Scheme of Research, 1925-26 (Revised Report), December, 1924, pp. 1-4
[270] Ibid., p. 7
[271] NA DSIR 23/2248 – Notes by SBAC on Additional Items of Research, March 1926. The items were a) Experiments on the best position of a monoplane wing, b) Experiments on the interference of centre sections with an aeroplane body, c) Experiments on various types of balanced controls, d) Experiments on combinations of various sections of wing and sizes of plane.
[272] Ibid.

provided an informal kind of research and testing which will be explored in a later chapter.

ATTEMPTS TO INCREASE LIFT, STABILITY AND CONTROL

Government research establishments were not the only source of important research and innovation in aeronautics. Private firms such as Handley Page developed crucial technologies which enhanced both the stability and safety of aircraft. While firms like Bristol made great strides in engine research, de Havilland improved the wooden aircraft and Supermarine innovated in both high-speed aircraft and flying boats, Handley Page can be credited with developing one of the most important technologies in the immediate post-war years, the slotted wing.

In his patent of 1920 H. F. Parker suggested that:

> The most important single problem in aeronautics awaiting solution is that of increasing the speed range of aeroplanes. In recent years maximum speeds have been increased very greatly, and will no doubt be still further increased, but each addition has been accompanied by an increase in the landing speed. The landing speed has always been about half the maximum and could not be reduced below that amount without entailing the expenditure of additional power. This is primarily due to the properties of the type of wing which has been used.[273]

This was a serious problem. Landing speed was always a crucial specification of any aircraft. The maximum landing speed dictated to an extent the maximum top speed which could be achieved. A variable camber wing, such as those suggested by Parker and Handley Page could offer a supplement in lift during take-off and landing. This in turn would give a greater degree of control over the aircraft at low speeds and speeds close to a stall, as well as greater flexibility in landing speed.

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[273] Parker, H. F., NACA, Report 77, *The Parker Variable Camber Wing*, (1920), p. 5

It was around 1925 that military aircraft began to move away from the First World War types. Aerodynamic work proceeding throughout the 1920s identified a number of problems to be solved. Most notably were the issues of stalled aircraft and aircraft entering into spins. The Aeronautical Research Committee report for 1924-1925 outlined that:

> Research upon the control of stalled aeroplanes has gone steadily forward throughout the year, the causes leading to defective lateral control in these circumstances having been thoroughly investigated by the Stability and Control Panel; the characteristics required in an aeroplane to make it controllable when stalled are now understood, and it has been demonstrated that these characteristics can be given by means of practicable modifications to the organs of control.
>
> It appears from the investigations that conventional aeroplanes, when stalled, are defective in two respects; they have insufficient rudder power and the ailerons when applied cause the aeroplane to turn and by doing so neutralize their direct effect on roll. It has been found by analysis, and proved by experiment, that either an increase of rudder power, or the use of an aileron which does not turn the aeroplane, would give the pilot power to regain an even keel from any position and so prevent the fatal spinning dive. Estimates of the increases in rudder power required to do this without using the ailerons have been made *and communicated to designers to provide an immediate cure for the worst forms of loss of control.*[274]

The report goes on to discuss the most successful 'cure' for stall and spin characteristics, the combination of the Handley Page slotted wing[275] and Bristol-Frise ailerons. The slotted wing was patented by Handley Page in 1919 but it is interesting to note that, as is often the case in aeronautics, a very similar design was first attempted independently of Handley Page by Gustav Lachmann (who later worked at Handley Page) in Germany. His idea came as a response to an air crash caused by

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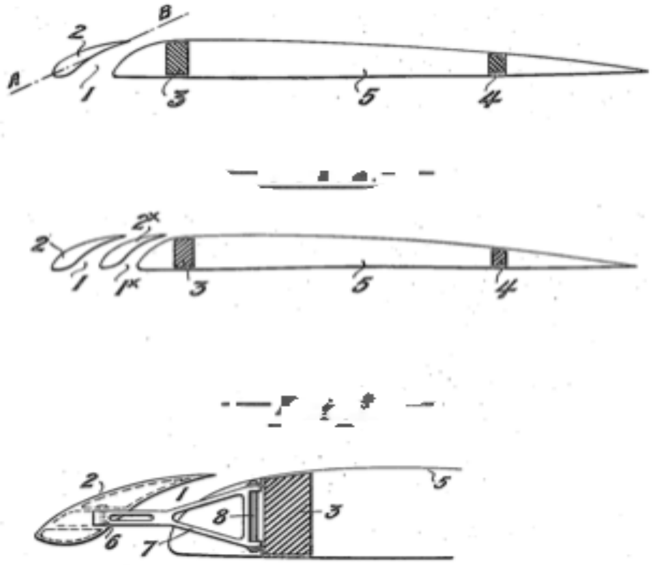
[274] NA DSIR 23/2074 – Aeronautical Research Committee Report, 1924-1925, Signed by ARC Chairman Richard Glazebrook, pp. 10-11 (My italics)

[275] Frederick Handley Page, "The Handley Page Wing," *Journal of the Royal Aeronautical Society* XXV, no. 126 (1921).

stalling. It was rejected, however, as the German patent office did not believe in the possibility of increasing lift by dividing the wing.[276]



Handley Page Slotted Wing (1920)[277]

Lachmann, writing in 1921, attributed the idea of increasing the lift of an aerofoil by subdividing it to experiments with gliders conducted by himself before the war:

> A crash in August, 1917, with a Rumpler C airplane, on account of stalling, caused the idea to be put into concrete form and presented for a patent in 1918. The patent claim reads: "Supporting surface characterized by its being divided into a number of tandem components which together form a wing section". The application was at first rejected because the patent office did not believe in the possibility of increasing the lift by dividing the wing. The issuing of the patent was made dependent on conclusive proof of such increase.[278]

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[276] Lachmann, Gustav, NACA, Technical Notes No. 71, *Experiments with Slotted Wings*, November 1921

[277] Handley Page, Frederick., *Wing and Similar Member of Aircraft*, U.S. Patent 1,353,666, Filed July 6, 1920. Patented Sept. 21, 1920.

[278] Lachmann, Gustav, NACA, Technical Notes No. 71, *Experiments with Slotted Wings*, November 1921, pp. 1-2

In 1922 Albert Betz[279] gave a lecture on the *Theory of the Slotted Wing* in which he discussed the two main ways the slotted wing was understood to work. However, he began his talk by discussing the origin of the slotted wing and its effects on aeronautical research and development:

> Through the intensive study of all technical aviation problems during the war, the most important airplane parts, especially the wing, were so thoroughly tested as to create the impression that no further substantial improvement was possible. The characteristics of the different wing sections were sufficiently known to enable one to select the most suitable section for almost any purpose.
>
> Then the discovery [of the slotted wing] by Lachmann and Handley-Page suddenly revealed entirely new possibilities and the wing section again became a rich field of problems…this discovery consisted in making one or more slots in the wing section. In this way it is possible to use the wing at higher angles of attack and thus considerably increase the lift…The advantage lies principally in the ability to vary the coefficient of lift, and hence the speed, within considerably wider limits. Hereby, the difficulties of taking off and landing are diminished and greater flight speeds made possible. Our knowledge of the behaviour of such slotted wings under the most diverse conditions is, unfortunately, very limited, and there is still much work to do before we shall have carried our investigations so far as to be able to choose, from the many possible modifications, the one best adapted for any given purpose.[280]

In this instance, the development of the variable camber wing opened up a new area for theorists, aerodynamicists and the like. The slotted wing to an extent redefined the problem of air flowing over an aerofoil; that is to say, the invention solved one set of problems and raised an entirely new set. Before the slotted wing, so much work had been done on optimum or definitive wing shapes, angles of incidence, thickness,

[279] Betz was a physicist and wind turbine pioneer. He was a researcher at the University of Göttingen aerodynamics laboratory and succeeded Ludwig Prandtl as the Director of the Aerodynamic Laboratory from 1936-1956.
[280] National Advisory Committee for Aeronautics, Technical Notes, No. 100, *Theory of the Slotted Wing*, Lecture by Albert Betz, 1922, pp. 1-2

chord[281] and so on that it was felt, as noted by Betz, that 'no further substantial improvement was possible'. The slotted wing allowed for greater speeds and reduced the difficulty of take off and landing by allowing a greater speed range. The problems raised by this invention, however, were concerned with the best type of shape, incidence, thickness and chord of the new auxiliary wing.

From reports published by the Aeronautical Research Committee from 1923-1927 it is clear that their highest priorities were stability and control of aircraft, particularly at low speeds, and the problem of spin. Research into improving the performance of aircraft was to be achieved by enhancing engine technology and work in aerodynamics. In 1926 the ARC considered that "The most important subject dealt with by the [ARC] is aerodynamics". By this time:

> Now that the subject of control in stalled flight which has occupied such a large portion of the available time during the past few years, has reached the stage at which its salient features are understood, more time has been available for the study of other matters now of equal importance. The mechanics of spinning have accordingly received considerable attention, and it is satisfactory to record that appreciable progress has been made and a better understanding of the notion has been reached. A good deal of further work, however, needs to be done in order that a detailed knowledge may be obtained of the steady spinning positions which aeroplanes of standard design can reach by means of conventional controls, and that the characteristics of an aeroplane which might lead to difficulty in recovering from a spin may be completely understood.[282]

Placing the mechanics of spin at the centre of ARC-directed research into aerodynamics had both practical and theoretical consequences. Wind tunnel work was conducted at the National Physical Laboratory and grants given to research the

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281 The width of an aerofoil from leading to trailing edge.
282 NA DSIR 23/2214 – ARC Report for the year 1925-1926, p. 11

problem elsewhere. For example, by the mid-1920s universities were becoming more fruitful sites of aeronautical research.

In a more practical sense, however, the ARC were strongly in favour of the Hill Tailless Light Aeroplane (the *Pterodactyl)* and funded research into the machine. It was the brainchild of Geoffrey T. R. Hill, an aeronautical engineer who was primarily concerned with the design and potential of tailless aircraft. More specifically, he was interested in developing aircraft which would never, through pilot error, get out of control. Hill felt the flying wing to be the best design for his purposes. From Hill's patent, filed in the United Kingdom in September 1924:

> The object of this invention is to provide apparatus which will permit aeroplanes to be controlled over a large range of flying angles, including the larger angles of incidence where under ordinary conditions the machine would become stalled and out of control. The invention comprises the employment of controlling surfaces angularly adjustable about lateral axes and situated in free air, not following wing surfaces.[283]

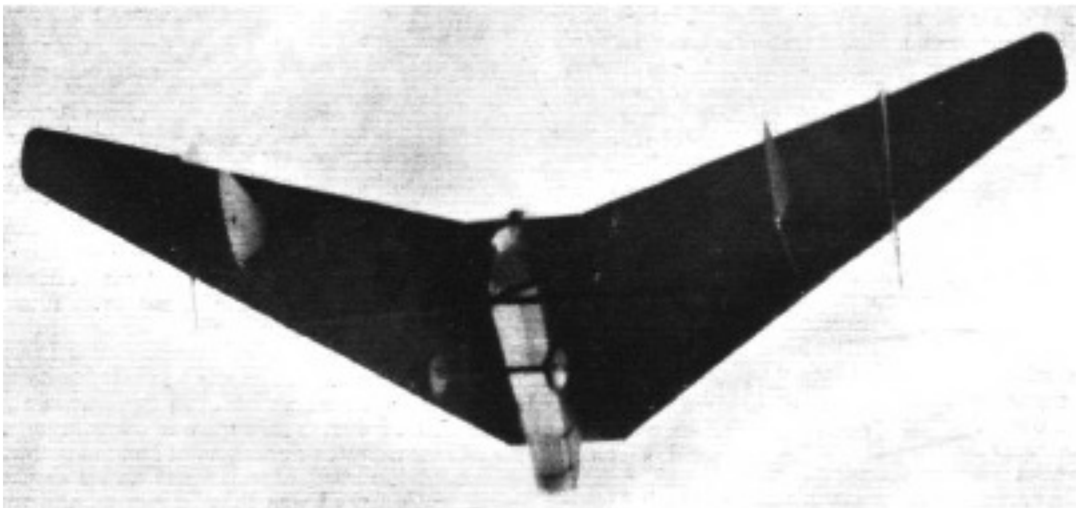

Figure 6 – Hill Tailless Light Aircraft 'Pterodactyl' (1926)

Tailless aircraft were seen at the time to offer aerodynamic advantages over conventional machines by increasing stability whilst reducing the overall drag penalty through the lack of a tail plane. The Air Ministry were very keen to subsidise work on

[283] Hill, G. T. R., *Control Surfaces for Aeroplanes,* U.S. Patent 1,600,671, Filed March 10, 1926. Patented September 21, 1926.

this type of aircraft and Hill's design was for the most part practical and a prototype glider powered by the Bristol *Cherub* engine convinced the Ministry to provide further funding.[284] Beginning in 1926 Hill and the Air Ministry embarked upon a series of designs none of which were produced in numbers but the evolution of the type is worth noting.

Following on from the Mark 1a, the next design produced to Air Ministry specification was the Mark IV under specification 16/29 in 1929. It was built primarily to demonstrate the practicality of the type and layout and was enough to convince the Ministry to release further funding to try and exploit the clear field of fire provided by the tailless pusher layout. The Mark V of 1932 represented a significant departure from the previous *Pterodactyl's*. The major change was from the pusher to tractor type layout which limited the unobstructed field of fire which was hoped for with the type.[285] It was of all-metal construction and performed well with a maximum speed of 190 miles-per-hour, a service ceiling of 30,000 ft and three machine guns. However, the project was then abandoned by the Air Member for Supply and Research:

> The abandonment of this specification is said to have resulted from the view of Air Vice Marshall Sir Hugh Dowding…who considered that the projected aircraft, with a pusher engine and a forward gun turret, did not represent a sufficient advance over the standard fighter aircraft of the day.[286]

Hughes' concept of the reverse salient in technological development is useful here. Wood to metal was a transition requiring development of many different components (the manufacture of exisiting components like struts and longerons in metal instead of

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[284] NA DSIR 23/2340 – Experiments on Pterodactyl I with Controllers of Different Sizes, 1926.
[285] NA DSIR 23/5362 – Development of the Pterodactyl Aeroplane, 1935
[286] Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*: p. 180.

wood, for instance). The concentration on stability over performance is another where components of the aircraft system had to be developed and advanced. The elimination of one reverse salient might solve that problem but raise several others. Ultimately development in all the components of an aircraft was necessary to facilitate change.

Another interesting aspect of this story which will be developed more fully in the next chapter is that in 1930 the Air Ministry experience a great deal of change and key positions in the Ministry changed hands. Hugh Trenchard, who for so long was the driving force of the RAF and had such a powerful influence over the selection of new types of aircraft and even new technologies was no longer Chief of the Air Staff, and Hugh Dowding became the Air Member for Supply and Research, a position which carried complete autonomy over the selection of aircraft for the RAF. These changes would prove to be highly significant factors in the shaping of aeronautical technology throughout the 1930s.

Early Air Force Doctrine and Strategy, 1919-1925

Besides the high degree of technical development carried out by designers working on aircraft such as the Schneider racers, aeronautical technology for the Royal Air Force was shaped largely by other pressures. The most notable shaping mechanism was the ring system implemented by the Air Ministry following the First World War. More so than anything else this system directly shaped aeronautical technology in both direct and indirect ways. Directly, the Air Ministry would ask for some feature or specification on an aircraft which, if not provided, would lose the tendering company business. Indirectly, this policy was to shape the way companies viewed risk for the next decade or more. Risk in design was not something to be tried. Trenchard was suspicious of technology or ideas which he did not ask for, and so the industry were less inclined to push the technological envelope. This is in contrast to a civilian company like deHavillands who operated outside of Air Ministry control and produced many innovated and progressive designs. The institutional doctrine, strategy and policy of the Royal Air Force was to play one of the major roles in the shaping of British aeronautical technology. As noted by Phillip Meilinger the terms ‘doctrine’, ‘strategy’ and ‘policy’ are sometimes used interchangeably but actually have distinct meanings, for instance:

> Doctrine, in essence, is a set of fundamental beliefs regarding the best way to fight wars and conduct campaigns. Doctrine is based on both theory and practice, and it tends to be relatively unconstrained by factors such as politics or economics that are crucial in war but which are not generally determined by military leaders. Ideally, practice should play the most important role in the formation of doctrine.[287]

Also relevant to this section is his definition of strategy:

> Strategy is the use, in peace or in war, of a variety of military, political, economic, cultural, or psychological levers in order to attain a country’s national objectives…A country’s political leaders determine goals, and devise a strategy to achieve them. Military leaders, in turn, use that guidance to devise a military strategy focused on achieving military objectives that will lead to the accomplishment of the country’s objectives.[288]

As he points out, for those working on developing a coherent air doctrine during the 1920s, there was very little evidence upon which to base it. U.S. Army General Billy Mitchell argued in 1925 that, “In the development of air power, one has to look ahead and not backward and figure out what is going to happen, not too much ‘what’ has happened”.[289] It was Mitchell, through a variety of means, who focused attention on the potential of the bomber in the United States at the expense of his career. Indeed,

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[287] Meilinger, "Trenchard and "Morale Bombing"," p. 244; ibid.
[288] *Ibid.* p. 245.
[289] William L. Mitchell, *Winged Defence: The Development and Possibilities of Modern Air Power, Economic and Military* (New York: Putnam, 1925). p. 20-21.

his outspoken critique of U.S. air policy throughout 1925 was to have a decisive effect on the future of U.S. military aviation.[290]

Meilinger goes on to say that in lieu of 'the main pillar of doctrinal formulation' (actual experience):

> …air thinkers came to rely on the other key input, theory. Air doctrine therefore became increasingly theoretical during the 1920s and 30s. *It was assumed that future technologies, equipment, and aircrews, although speculative and untested at the present, would provide definable results*. In truth, these exercises in logic, although articulate, cogent and seemingly rationale, were still theoretical.[291]

The doctrine and strategy of the Royal Air Force during the early 1920s had been largely formed by the experiences of aviation in the First World War and underpinned by the seminal work *Command of the Air* (originally published in 1921) by Giulio Douhet who advocated strategic bombing of enemy industry and infrastructure and believed that sufficient pressure from bombing civilian populations would break the will of the people.[292] For British theorists it was a case of inference and extrapolation. Inferences drawn from British experiences of German bombing raids during the First World War were then extrapolated to allow for assumed continuing improvements in aviation technology. Reflecting upon the effects of German bombing during the war was fairly widespread, with the following a typical assessment:

> The enemy's primary motive was to undermine the morale of the British public. He realised that the moral effect of bombing from the air and its various secondary consequences, such as the stoppage of railway traffic and reduction in the output of munitions, far outweighed the somewhat limited material damage possible. Although it may justly be claimed that the failure of the German effort to achieve any considerable moral effect was due, firstly, to the pin-prick nature of the raids themselves, and, secondly, to the success of the defensive measures which

[290] Gibbs-Smith, *Aviation - An Historical Survey*: p. 185.
[291] Meilinger, "Trenchard and "Morale Bombing"," p. 245. (My italics).
[292] Giulio Douhet, *The Command of the Air* (London: Faber & Faber, 1943).

were extemporised, we cannot ignore the effect of the raids, which decreased our munition output and obliged us, in response to public demand, to retain valuable material and personnel in this country. For instance, the defence of London alone employed 14 service squadrons, 10 balloon aprons, 370 searchlights, 180 guns and some 30,000 men.[293]

In 1921 the Air Staff addressed its theory of aerial warfare:

> One half the aim of an offensive air policy was moral effect. If there were no defensive aircraft [fighters] it would affect national morale adversely before the enemy had arrived at all; we would thus be playing into the enemy's hands…night bombing produced the greater moral effect, but this moral effect could be produced with comparatively small numbers of aircraft by night…All agreed that it was not necessary to despatch a weight of bombs by night as by day; but continuous bombing throughout the whole night was essential.[294]

This was a view shared by the Chief of the Air Staff Hugh Trenchard who was a firm believer in the idea of 'morale bombing' and that the development of bombers should be of paramount concern and, if nothing else, should act as a deterrent to aggressors. He agreed with Douhet's Total War mentality that said bombers should be employed against enemy industry, infrastructure and civilian populations with the aim of destroying their will to fight. Trenchard's views were succinctly summed up in 1923, a time when France was considered to be the main threat to Britain, when he said:

> Would it be best to have less fighters and more bombers to bomb the enemy and trust to their people cracking before ours, or have more fighters in order to bring down more of the enemy bombers. It would be rather like putting two teams to play each other at football and telling one team they must only defend their own goal, and keep all their men on that one point. The defending team would certainly not be beaten, but they would certainly not win, nor would they stop the attack on their goal from continuing…I feel that although there would be an

[293] W. T. S. Williams, "Air Exercises, 1927," *Royal United Service Institution Journal* 72(1927): p. 739.
[294] NA AIR 5/564 – Papers and Conference Re: Air Menace, Meetings of the A.A. Defence Committee, 10th and 11th November 1921

> outcry, the French in a bombing duel would probably squeal before we did…The nation that would stand being bombed the longest would win in the end.[295]

This view was echoed by Deputy Chief of the Air Staff (DCAS), John Steel:

> There is in the air no such thing as absolute destruction and defeat of the enemy air forces. However much his pilots and machines suffer, the enemy's resources are still there and he can (perhaps with much inconvenience and interruption) go on building aeroplanes and training pilots. There is always hope, so long as the invading army can be kept away and so long as the civilians hold out…[296]

It is interesting to note that over a decade later these beliefs had not changed. In 1932 Prime Minister Stanley Baldwin said in a speech to Parliament that "the bomber will always get through. The only defence is offence which means you have to kill more women and children more quickly than the enemy if you want to save yourselves".[297]

The idea of an offensive bombing strategy was to cripple enemy industry and break the will of the enemy population. The debate amongst historians over the operational roles of the RAF is concerned with whether or not an offensive bombing strategy was pursued at the expense of a strong aerial defence (which would necessarily incorporate a number of fighter aircraft) of Britain in the 1920s, and at what point aerial defence became an important consideration for the RAF. Largely, the historiography points to the belief that British air defence did not begin until 1934 and even then simply because radar technology became available.[298] John Ferris has

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[295] NA AIR 19/92 - Home Defence: scheme for expansion of the R.A.F., Minutes of Meeting in CAS's Room, 19th July 1923

[296] NA AIR 5/328 – Correct objective for air forces regarding air strategy in Home Defence, Memo by Deputy Chief of the Air Staff, John Steel, 6th July 1923.

[297] Stanley Baldwin, "Mr Baldwin on Aerial Warfare - A Fear for the Future," *The Times*, 11th November 1932.

[298] H. Montgomery Hyde, *British Air Policy between the Wars, 1918-1939* (London: Heinemann, 1976). pp. 322-24. John Terraine, *The Right of the Line: The Royal Air Force in the European War, 1939-1945* (London: Hodder and Stoughton, 1985). pp. 19-22. Malcolm Smith, *British Air Strategy between the Wars* (Oxford: Clarendon Press, 1984). p. 79.

disputed this thesis, arguing that Trenchard's view (that sustained bombing of enemy population centres was the most effective use of air power) was gradually marginalised in the face of a growing number of Air Ministry staffers who believed that an effective strategic air defence could be achieved. "Virtually alone, Trenchard argued that strategic air defence was impossible".[299] Almost everyone else, however, was of the opinion that it could be made to work and that the Home Defence Air Force should be pursued as a top priority "equalling the development of a bomber force".[300] On the subject of air defence and the need for a strong fighter development programme RAF Flight Lieutenant C. J. Mackay considered, in 1922, that "the primary weapon with which aircraft must be fought is aircraft; too much emphasis cannot be laid on this point".[301]

Discussions held in 1923 between high-level members of the Air Staff and recognised experts in the field of air defence help to illustrate that the balance of opinion was that research be divided equally between an offensive bomber force and such technologies to be used for the location and destruction of enemy formations:

> To my mind in an air war if it comes 5-10 years hence the improvements in sound locating and W/T [wireless telegraphy] and R/T [radio telephony] will cause all enemy's attacks to be closely followed and aircraft of the defence concentrated to meet them. There will be less and less evasion and more and more fighting to reach one's objective.[302]

Indeed, by 1924 some kind of balance had been struck between bombers and fighters, with six types of the latter and nine of the former under various stages of

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[299] John Ferris, "Fighter Defence before Fighter Command: The Rise of Strategic Air Defence in Great Britain, 1917-1934," *The Journal of Military History* 63, no. 4 (1999): p. 849.
[300] Ibid.
[301] C. J. Mackay, "The Influence in the Future of Aircraft upon Problems of Imperial Defence," *Royal United Service Institution Journal* 67(1922): pp. 278-79.
[302] NA AIR 5/328– Air Officer Commanding India, Chamier to DCAS Steel, 10th January 1924

development.[303] Still, by 1925 Air Staff opinion looked towards developing the best fighters possible for a home defence force, and indeed to blend the functions of the fighter and bomber under certain circumstances: "There is no doubt that in the future single-seaters will be required to attack ground targets with bombs. This will be so particularly in small wars".[304] They went further, however, by suggesting the need for a second type:

> The fighter…will not be of much use in a first class war (e.g. against France) when opposed by the fastest modern single-seaters. It seems absolutely necessary to have this type for army co-operation in small wars and for night fighting in any war, but it seems a pity to let the big military required for these duties stand in the way of the production of the really first class high-performance fighter which will be needed for day fighting in home defence and in any European war.[305]

Crucially, the Air Staff distinguished between Imperial/Colonial defence and "any European war", and it must be remembered that throughout the 1920s the most pressing duties performed by the RAF were actions against insurgent populations of British colonies:

> The aeroplane…can be located within [the] typology of technological imperialism, of which the police bomber was in some respects the culmination. The main concern of air policing was with the consolidation of imperial power, but aircraft were used in all three technical phases. They penetrated territory little known to Europeans, mapped areas obscure to the imperial power, and – when equipped with floats – used rivers as routes of access to the interior. During the phase of conquest, bombers were used to crush 'primary' resistance movements: during the phase of consolidation they helped break rebellions against imperial rule. Once a

[303] NA AIR 20/68 – Aircraft Development Programme, List of Aircraft Constructed or In Hand, 2nd January 1924, pp. 1-2
[304] NA AIR 20/70 – Development of Fighter Planes, 'Military Load of Single Seat Fighters, 1925, p. 2
[305] *Ibid.,* p. 3

region had been brought under nominal European sovereignty, aircraft helped to extend state power to marginal areas of swampland, mountains or deserts.[306]

The assumption made was that for such colonial policing there was no particular need to spend vast sums on developing military aircraft with higher performance, the unruly populations of overseas colonies had no air force and so the relative performance of aircraft was simply not an issue. However, it was keenly felt that should there be a war with any European power that the pursuit and development of a first class fighter would be crucial. That being said there were still movements to develop special types of machine based around colonial policing:

> Discussions on a [single seat] armoured machine: This subject has, of course, been under consideration for many years but it was disposed of temporarily in June 1924…it was laid down that armour could not be used in aircraft until a lighter form of armour plate was produced, or until some other improvement in aircraft, such as a greatly increased performance, was made. The matter remained dormant until the [Secretary of State for Air] brought it up again as the result of casualties during the last Akhwan troubles. S. of S. thinks the specialised ground strafing which we indulge in in Iraq warrants the consideration of developing a special type of machine.[307]

It seems, then, that the effects of doctrine and strategy in the 1920s on the shaping of aircraft technology had more to do with what kinds of aircraft to develop rather than individual component technologies such as engines, propellers and so on. There was simply no urgency, no need for the highest performance machines that could be attained. That would change in the 1930s with the rise of Nazi Germany and their increasingly aggressive foreign policy, but the main consideration in the 1920s was an offensive bomber doctrine and a strategy of colonial policing that did not require a technological revolution and did not present any crisis or pressing need for radical

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[306] Omissi, *Air Power and Colonial Control*: p. 4.
[307] NA AIR 20/68 – Aircraft Development Programme, Wing Cmdr Welsh to DCAS, 'Remarks on Experimental Aircraft Programme, 2nd October 1928

new aircraft technologies to be pursued. Development continued, however, and the next chapter attempts to illustrate how fragmented and gradual a process it was, beginning with attempts to increase lift and improve the stability of aircraft in the air.

Chapter 3: 1925-1930

The Air Staff and the Metal Debate, 1924-1930

Definitive interest in the all-metal machine and the decision to pursue an all-metal agenda for the RAF first came around 1924-25. It is worth noting that the Air Member for Supply and Research (AMSR) at that time had complete autonomy over which machines to order and could, if he chose to do so, completely ignore the wishes of the Air Staff.

> Whatever the source of a proposal for a new aircraft, they were all regarded as experimental, and were brought together in annual Experimental Aircraft Programmes. These programmes were drawn up by the AMSR's department and discussed with the Air Staff, but the AMSR could, and did, proceed with projects which were not approved by them.[308]

By 1925, AMSR and others such as the Director of Contracts (D. of C.) considered that all-metal construction was the best way forward for the Service: "Metal Construction will be imperative in war and the proposed step will be a real advance".[309] Plans were discussed and then set in motion to bring the industry in to line with Air Ministry thinking. D. of C. noted in 1925 that:

> I quite see that firms, especially the weaker ones, will shrink from the capital outlay entailed by preparation for metal construction, and that if left to themselves things will drag on for a long time. Hence, the importance of a fixed date.[310]

The problem for the Air Staff was to somehow persuade the industry to convert to metal construction and, therefore, to spend the capital required in making such a change. As D. of C. mentioned above, this would not be easy, requiring the firms to spend a great deal on new tools, proper jigs, not to mention changes in labour and the "acquisition of knowledge and practice of metal processes".[311]

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[308] Sinnott, *The R.A.F. and Aircraft Design*: p. 30.
[309] NA AIR 2/1208 – Equipment of the RAF with all-metal machines, Policy, 1925-1932 – Memo, D. of C. to AMSR, on capital outlay for construction of all-metal machines, 09/11/1925
[310] Ibid.
[311] Ibid.

It was decided that it would take four to five years for the industry to be able to make such a change and yet the question remained as to how best to make the industry fall in line with such a plan. It was believed that:

> …mere exhortations to the firms will not be efficacious. [One] course would be to send a circular letter here and now to all the firms to the effect that we had decided at no distant date to equip the RAF with metal machines. That within a short period a date would be notified after which the Ministry would order only metal machines and that it would be advisable for firms to decide whether they wished to be considered for metal production, having regard to the fact that considerations of cost point to the profitability of large order to a much smaller number of firms than at present exists.[312]

Despite this strong movement in favour of as rapid a change to metal construction as could be managed, other voices within the Air Staff were not as convinced, most notably the Chief of the Air Staff, Sir Hugh Trenchard. He was partly in favour of metal construction but was highly skeptical of the time frame aimed for by AMSR and D. of C.:

> …I see that metal construction is the basis of the whole scheme. I feel that although we might try to work towards metal construction, this alone will take several years before we can make any decision as to whether all the machines must be of metal construction, when one considers the negligible number of metal machines we have now in being, on order, or even forecasted.[313]

This was directly at odds with the ideas of AMSR and D. of C. They wanted the industry to switch to producing metal aircraft to remain up to date in warfare, considering it "imperative"; Trenchard in his role as CAS believed that it would take years before they could say if they even needed all machines to be manufactured in

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[312] Ibid.

[313] NA AIR 2/1213 – Scheme of Production of Aircraft in Peace and Development of War Reserve and Organisation of the Industry to Meet the Situation which would Arise in an Emergency – CAS to Secretary of State for Air on AMSR Minute, 11/07/1926, p. 1

metal. The differing attitudes illustrate the fact that switching to metal construction was not a simple matter and its importance and the rate of change was debated at the highest levels of the Air Staff. Hence, it was more a question of how long it would take rather than any specific objections to metal construction. Trenchard's attitude to the proposed changes seems in a sense more measured than AMSR or D. of C., although some would call it a regressive, unimaginative outlook.[314]

It is worth noting that traditionally it has been the Air Ministry and Air Staff that have come under fire for delays in moving to metal and that these delays stemmed from a lack of enthusiasm for the new technology. However, I would suggest that attempting to paint a straightforward picture about the choices made and who was to blame for delays and so forth is actually misleading and not at all helpful if we actually want an accurate sense of what happened and why.

As mentioned above, there was a distinct worry about adopting metal machines without ground crews adequately trained in the repair and maintenance of metal machines. Indeed, until 1927 there was no such infrastructure for the training of such crews. A scheme for training apprentice aircraftmen was begun in 1920 and each year there was a call for recruits, each year there were three positions available to train for; 'carpenter-rigger', 'aero-engine fitter' and 'wireless operator-mechanic'. The 'carpenter-rigger', as the name suggests, would be responsible for the repair and upkeep of wooden machines, or those of a wood/metal hybrid. In 1927, however, there was a call for 600 vacancies to be filled and for the first time the 'metal rigger' position appeared.[315] It is significant that the RAF and Air Ministry were creating an

[314] Barnett, *Audit of War*. The picture of inter-war aircraft development that Barnett paints is one of a technically underachieving industry and backwards looking Air Ministry.

[315] Anon., "600 Vacancies as RAF Aircraft Apprentices," *Flight* XIX, no. 29 (1927).

infrastructure to support the changes in aircraft design that they knew were coming, and from 1927 those people training to become ground crew were trained to deal with metal structures.

The aircraft industry itself has also come under fire for being “unprogressive compared to the continent, and later the United States”.[316] The charge is that when building machines of metal, constructors should have taken the opportunity to make major design changes resulting from the “inherent lighter strength of the metals which makes them suitable for the construction of cantilever wings”.[317] Hoff means metal monoplanes, and it is interesting to note that for historians it is not the performance of aircraft that illustrates success or failure but by 1930 it is very much the form, the structure and the materials that mark a successful, modern, or progressive aircraft.

Comparing any aircraft with another can be a tricky business and one must be careful not to misrepresent the purpose of a machine as its operational role will affect the nature of its performance and handling characteristics as well as its structure and form. However, carefully controlled comparisons, made to illustrate one particular point, can be of some use in explaining why judgements such as those of Hoff above are without much value. It would be one thing to make such assertions as to the conservatism of the British aircraft industry if competing aircraft in other countries were achieving significantly higher performances than their machines, but in the 1929-33 period this was not the case. Again, however, attempting to determine which nation had the faster aircraft or the most ‘modern’ aircraft and so on does not help us determine how and why choices were made.

[316] Gibbs-Smith, *Aviation - An Historical Survey*: p. 183.
[317] N. J. Hoff, "A Short History of the Development of Airplane Structures," *American Scientist* 34, no. 2 & 3 (1946).

It is clear that in the years after the First World War the consensus amongst designers in Britain was to continue in the wood-metal hybrid, or all-wood vein. Substantial capital outlay would be required in order to adequately tool-up for a full-scale shift to metal aircraft.

AIR STAFF PLANNING AND TECHNICAL DEVELOPMENT IN PEACETIME (I)

By 1926 Air Staff thinking was still firmly in the grip of the so-called 'ten year rule' but a report carried out into the procurement process for the RAF by Air Commodore Charlton[318] began a debate within the Air Ministry about the future of this policy and its technical ramifications. Particularly, the debate centred around a plan for the future which would allow for an adequate peacetime Air Force which maintained high technical standards and provide a cogent strategy for the re-equipment of the Royal Air Force. In response to Air Commodore Charlton's survey of the aircraft industry the Air Member for Supply and Research considered that the adoption of a regular, systematic programme for the equipment of the RAF in peace, and organisation in peacetime of an industrial system for war production would be necessary.[319] Furthermore, he prescribed a much leaner system of aircraft development and procurement emphasising far more standardisation amongst types and designs of aircraft. For instance:

> Systematic Programme of Equipment of RAF in peace.
>
> 1. Metal construction of aircraft to be adopted as the basis of the whole scheme.

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[318] NA AIR 5/1368 – Air Commodore Charlton's Report: Survey of the Aircraft Industry and Allied Trades, together with Recommendations and Emergency Production, 1924-1925

[319] NA AIR 2/1213 – Scheme for Production of Aircraft in Peace, AMSR to CAS, 2nd July 1926, p. 1

> 2. Each main type of aircraft (i.e., single-seat fighter, etc.) in use by the RAF to be replaced once in five years.
>
> 3. One design only (Horsley, Fox, etc.) to be in standard use by the RAF for each type.
>
> 4. On re-equipment after five years' service all aircraft of a type being replaced to be transferred to and held in reserve for 10 years complete with engines and accessories.
>
> 5. Development of a new design of a type to be put in hand as soon as the previous design is taken into service as standard by the RAF.
>
> 6. Specification, construction and trials of experimental aircraft, construction and service trials of development aircraft, incorporation of all modifications, organisation for peace production of new design to be complete in 5 years so as to replace previous design.[320]

This plan assumed continued technical progress in both airframe and engine design to the extent that it would be worthwhile replacing complete designs every five years, but it also aimed to solve problems plaguing the design and adoption of new types of aircraft for the RAF. Continuous interference on the part of the Air Staff meant that modifications were constantly to be made in the stages of design and production as well as when the aircraft were actually in service.

The Society of British Aircraft Constructors (SBAC) had highlighted this problem as early as 1925:

> The present position in aircraft design in this country has, in the Society's opinion, been brought about by rather too much restriction on design and equipment and to changes which the designer is called upon to make in the course of construction.[321]

Robert Brooke-Popham also discussed the subject a little later in 1930:

> When service aircraft takes [to] the air with its full equipment on board, it looks like a neglected bramble hedge owing to the vast number of excrescences in the form of service equipment. What is the use of designers streamlining their machine?...we require navigation lamps and identification lamps which are streamlined into planes and fuselages instead of

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[320] *Ibid.,* pp. 1-2

[321] NA AIR 20/68 – Aircraft Development Programme, Letter from SBAC Secretary Charles Allen to the Air Ministry, 7th February 1925

being stuck on the end of brackets and which do not require young power stations to work them![322]

Frederick Handley Page also weighed in:

> …the open cockpits, projecting gunrings and guns, pumps and other excrescences of the present fuselages add to resistance and tend to reduce all aircraft to one common level of inefficiency.[323]

The plans from AMSR in 1926, therefore, attempted to provide a cohesive method for aircraft to be designed, modified if necessary and tested by the time existing service types were due to be replaced. It also aimed to cut down on the variety of aircraft designs used to fill a particular type and so reduce the number of designs in use by the RAF.

CAS Lord Trenchard was not enthusiastic about the majority of these plans, doubting whether all RAF aircraft should be metal and whether they could make any plans actionable in less than two years. Again, it is interesting to take note of the influence Trenchard had, not simply over technical choice, but over the whole system of design and development of RAF aircraft. One fairly unique example comes from the Fairey *Fox* test pilot, Norman MacMillan:

> I remember the occasion as if it were yesterday. After my flight demonstration the CAS asked me to accompany him apart from all the others and we walked on to the grass of the airfield well out of earshot. There the CAS asked me what I really thought of the Fox; did I think it was an aeroplane that could be handled safely by young and less experienced pilots of the RAF? I told him frankly that it was one of the easiest and most viceless aeroplanes I had ever flown. We walked back to the hardstand, and Sir Hugh Trenchard looked at Dick Fairey and said…"Mr Fairey, I have decided to order a squadron of Foxes".[324]

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[322] *Ibid.,* F.O. 1 to DCAS, 'New Aircraft Programme for 1931-1932', 6th October 1930, pp. 6-9

[323] J.D. Prentice, "Aircraft in War in Ten Years Time," *Royal United Service Institution Journal* 74(1929): p. 706.

[324] Taylor, *Fairey Aircraft since 1915*: pp. 137-40.

On the subject of AMSR's proposals CAS said:

> In my opinion, it will take at least another year or two before we can come to any decision on all the points put forward here. I see…that it is necessary to adopt a systematic programme for the equipment of the RAF. This I agree should be striven for, but it will not be practicable for many reasons.[325]

Essentially Trenchard's memo to the Secretary of State for Air sounded a cautionary tone, warning against moving too fast and decrying any attempts to speed up the time from the issue of a specification, to the development of a prototype and finally a production aircraft. As mentioned in the previous chapter, however, the Air Staff had decided by 1925 that from around 1930 only all-metal machines would be considered (again, all-metal in this instance simply means an all-metal frame, allowing for a fabric skin). Trenchard's concern was that reducing the process from seven to five years might not provide enough time to swap existing machines with the best possible replacements. He was, however, of the opinion that certain points put forward by AMSR should be considered, namely:

> 1. To try and move towards metal construction.
> 2. To press towards the adoption of only one design of machine for each type of duty.
> 3. No machine should come into the Service until it has had, besides the technical trials, a preliminary Service trial of a month, and a trial by a whole Squadron for a year, before ordering in greater numbers.
> 4. That a machine should be held in the Service for a period of 7 years, which period could be reduced if it is found possible to produce machines more quickly.
>
> It seems to me that it is necessary to choose a few points in the report and settle them, as a means of illustration for the settlement of other points in the future.[326]

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[325] NA AIR 2/1213 – Scheme for Production of Aircraft in Peace, CAS to S. of S. for Air, 22nd July 1926, p. 1
[326] *Ibid.,* p. 7

Director of Contracts (D. of C.) appraised AMSR's proposals more favourably, however, commenting from a finance and contracts perspective:

> …I am bound to sympathise with the object of any proposals directed, as AMSR's are, to a greater degree of regularity and systematisation of the aircraft and aero-engine programmes…I hope, however, that if the procedure suggested by CAS is adopted, the need for working towards a more regular and consequently economical system of demand and production will be kept steadily in view during the discussions as a practical requirement by all concerned.[327]

The main disagreement between CAS and AMSR was the timescale. Indeed, AMSR reported that he was "very concerned with [CAS's] idea that nothing definite can be done for another 12 or 18 months and that the matter is not one of urgency, in view of the Cabinet's decision that no first-class war need be provided for until 1938".[328]

> It is not simply a question of providing for a production organisation for war. As I pointed out…it is one of the features of Air Commodore Charlton's scheme that it promises a solution of the present highly unsatisfactory position of the Air Ministry with regard to the aircraft industry…the root of all these difficulties is to be found in: (a) the unnecessary number of firms at present in the industry, and, (b) the perpetual uncertainty as to the orders which any firm will get owing to our present method of placing orders. This position of affairs cannot be cured merely by palliatives such as we are now obliged to resort to in order to keep firms in being for a short time longer. There must be a revision of our system of ordering. Until that system is revised our expenditure on supply will continue to be wasteful to ourselves without even being correspondingly profitable to the industry.[329]

With this memo, AMSR was attempting to highlight the wasteful nature of the current scheme of ordering, but he was also relating it to problems with the 'ring system', organised for keeping the industry alive and in the business of designing and

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[327] *Ibid.,* D. of C. to S. of S. for Air, 19th July 1926
[328] NA AIR 2/1213 – Scheme for Production of Aircraft in Peace, AMSR to CAS & S. of S. for Air, 29th July 1926, p. 1
[329] *Ibid.,* pp. 1-2

manufacturing aircraft during the 1920s. He was also concerned that in delaying such plans as to bring greater stability and systematisation to the process of designing and ordering aircraft for the RAF, there was a risk of falling behind in a technical sense, that in not pressing for the best technology and its implementation into Service aircraft there remained a very real possibility of potential rival air forces gaining a technical and tactical edge over the RAF. The idea that RAF procurement was not, and would not become, an urgent matter until some short time before 1938 was to him a dangerous one, and a problem that could be solved by reducing the time between commissioning new aircraft and thus also providing more regular opportunities to implement newer, and presumably more advanced technologies into Service aircraft.

In 1927, Robert Brooke-Popham stated that:

> I feel certain that we must go on asking for what are stated to be impossibilities. We have just about got now what we asked for as far as I can remember, in 1916, but we never should have got it in 1927 if we had merely asked for what we were told we could get in 1916.[330]

Brooke-Popham therefore believed that asking designers for more than was available provided valuable stimulus to the design and innovation process.

As an example of this, in 1927, Deputy Director of Technical Development (DDTD) wrote a memo outlining the benefit of sacrificing the top speed of certain Service machines:

> I understand that for some time we have adopted certain arbitrary landing speeds for various types, and on the whole wisely. What I am not clear about is whether you have had alternatives put clearly before you and are satisfied that we have invariably chosen the best compromise. Would it interest you, for example, to know that a sacrifice of:
>
> 3 m.p.h., top speed on the Siskin
> 2 m.p.h., top speed on the Horsley
> 1 m.p.h., top speed on the Virginia

[330] NA AIR 20/70 – Development of Fighter Planes, Jan. 1925 – Oct. 1940, R. Brooke-Popham to Director of Operations and Intelligence, Mr. Newall, 8th July 1927

will give you a design offering not only a landing speed in each case 10 m.p.h. slower, but a climb improved by around 10%. The service ceiling would also rise from

27,000 ft. to say,	30,000
15,000 ft.	21,000
7,500 ft.	9,000

To my mind there is little question that the slower machine is much the finer proposition. Even on the Siskin the loss of 3 m.p.h. top speed seems to me more than compensated for by the much improved climb and ceiling giving the upper gauge so much more readily, and improved handiness.[331]

Deputy Director of Operations and Intelligence (DDOI) replied by explaining how Service aircraft came into being:

The points raised by DDTD are interesting, but I cannot see the object of bringing them up. All specifications for new types are put through the Air Staff for any remarks they may have to make. In some cases the type is discussed by the Air and Technical staffs before the specification is prepared; an example is the Interception Fighter we recently asked for. It is surely the obvious duty of the technical staff to advise us from every point of view as to how our various requirements may affect the design of a type. With the few types we have considered lately this has been done, but I doubt very much if it was on the three machines given in the example [by DDTD]. The Virginia and Siskin were produced at a time when the Home Defence Force was being rapidly expanded, and both were such vast improvements on existing types that they were willingly accepted. The Horsley was one of four competitors in a class of which it was the only private venture, it was accepted without the Technical staff having anything to do with it.

In the latest specification (Partridge) even a freer hand has been given to the Technical Department; we have only asked that the speed at 15,000 ft should be as great as possible and the landing speed not more than 52 m.p.h. I do not know what greater margin could be allowed, but it is certain that whatever we ask for we shall be given something inferior…But there is one point that DDTD seems to have forgotten. The fighter is a cheap machine to experiment with and to build, and to the successful designer there is always a large

[331] NA AIR 20/70 – Development of Fighter Planes, Jan., 1925 – Oct., 1940, DDTD to DDOI, 'Performance', 26th May 1927

market. The result is that the majority of fighters that are offered to the Air Staff are private ventures built to no particular specification. The designer has therefore a free hand and the machine is accepted usually because is has a better performance than existing types. It is then probably too late to bring in any of the alternatives mentioned by DDTD.[332]

DDOI went further in writing to the Deputy Chief of the Air Staff that:

> As regards fighters I cannot agree with DDTD. In time of war the demand is for greater top speed and climb, while slow landing speed is scarcely considered. In peace time, on the other hand, there is always a tendency to sacrifice high speed to those other factors which contribute towards safety. Personally, I would rather ask DDTD to say what would happen if we ask for an additional 10 m.p.h., top speed on the Siskin IIIA.[333]

The examples cited by DDTD were introduced around 1922-1923 and by 1927 ordering and development procedures were becoming more standardised. DDOI mentions above that the majority of fighters offered to the Air Staff were 'private ventures built to no particular specification', while that is not strictly true as the Air Ministry offered plenty of specifications covering fighter aircraft of various types, the specification process became far more rigid in the later 1920s and early 1930s. However, specifications were an integral part of Air Ministry procurement, AMSR had set out in 1924 that:

> I think the procedure should be as follows:
>
> a. We should issue to all approved firms a specification for the machine it is desired to produce, asking them to tender by a certain date for the production of one machine.
>
> b. When the tenders have been received, four selections will be made, of which two will be the lowest tenders and two will be arbitrarily selected according to various circumstances, such as:
>
> i. Special capacity of the firm for the type involved.
>
> ii. Amount of design work in hand already.

[332] Ibid., DDOI to DDTD, 'Performance', 2nd July 1927
[333] Ibid., DDOI to DCAS, 'On DDTD Performance Memo', 4th July 1927

> c. As soon as possible…comparative trials will be held, including service trials, with a view to arriving at a decision as to which machine is to be selected either for the service or further development…[334]

Unsurprisingly, perhaps, the Society of British Aircraft Constructors (SBAC) considered that "the specification should be worded as broadly as possible" and that it should be "a statement of requirements rather than a specification".[335] The SBAC also thought that rather than the Air Staff picking the aircraft based upon price, they should instead state the price they were prepared to pay "and it should be the business of aircraft designers to give the best possible aircraft within the price laid down".[336]

However, before the Air Staff were able to issue any specifications decisions had to be made on what types of machine to concentrate on, for what sort of operational roles and so on. A conference was held in 1926 to look at the new programme of experimental aircraft for 1927-1928.[337]

The table below outlines the growth in performance of some of the RAF's first line fighter aircraft between 1923 and 1931. What can be seen is a gradual but steady increase in speed, a faster rate of climb and a higher service ceiling. The service ceiling of an aircraft is the altitude at which an aircraft will be expected to produce a given rate of climb, roughly 100 ft/30m per minute.

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334 NA AIR 20/68 – Aircraft Development Programme, Memo from AMSR, 28th November 1924

335 Ibid., Letter from SBAC Secretary Charles Allen to Air Ministry, 7th February 1927

336 Ibid.

337 Ibid.

Year.	*Type.*	*Best Speed.*	*ROC to 15,000*	*Service Ceiling*
1923	*Grebe.*	*146 m.p.h. @ ground level.*	*14.24 minutes*	*22,000 ft.*
1925	*Gamecock.*	*151.5 m.p.h. @ 5,000 ft*	*13.15 minutes*	*23,000 ft.*
1927	*S/Charged Siskin.*	*149 m.p.h. @ 7,000 ft*	*13.7 minutes*	*24,500 ft.*
1929	*Bulldog.*	*177 m.p.h. @ 9,000 ft*	*9.75 minutes*	*28,800 ft.*
1931	*Fury.*	*205 m.p.h. @ 13,000 ft*	*7.37 minutes*	*29,000 ft.*

Growth in Performance by British Aircraft (Fighters)[338]

Perhaps the most important factor in improving all of these aspects of aircraft performance is the engine. Rates of climb are affected by many different factors, for instance, the wing span, weight of the aircraft, parasitic drag coefficient, propeller efficiency, and so on.

THE SCHNEIDER TROPHY, 1913-1931

An interesting aspect to the story of inter-war aircraft development is that of the Schneider Trophy. Within this story there are two aspects of particular significance to this thesis. First, the races provided a valuable stimulus for new technology in paritucular areas. The focus was on the improvement of aerodynamics and the overall structure of the aircraft in a constant effort to achieve better performance. Secondly, the races were significant as they demonstrated new and cutting edge technologies.

While by no means the only air race in the world, it was certainly the most significant. Aircraft competing for the Trophy routinely set world speed records. The races themselves drew vast crowds, and the competition evolved from one where machines were largely funded privately to one where the interests, and money, of the state were closely intertwined with the outcome. It became a matter of national pride, and as

338 NA AIR 20/70 – Development of Fighter Planes, Jan., 1925 – Oct., 1940. Growth in Performance by British Aircraft, undated, likely 1931.

such, state involvement and funding grew from minimal assistance in development to one of near total financial control and the expenditure of vast amounts of money. There was, however, at least in Britain, the idea that money spent on Schneider racers would reap some kind of technical reward in the design and development of future aircraft for the Royal Air Force, and in many ways (speed, integration of aerodynamic theory and airframe form, for instance)[339] they set a benchmark to be hit by future designs. Of course, meeting these standards was not immediately possible as Schneider aircraft were optimised purely for speed. Engines were designed and tuned so as to generate enormous power outputs by the standards of the time and had very short operational lives, but the real advances were made in the science of aerodynamics. The design of the Schneider aircraft changed radically between 1921 and 1931:

Figure 7 - Macchi M. 7bis (1921)

[339] Ermanno Bazzocchi, "Technical Aspects of the Schneider Trophy and the World Speed Record for Seaplanes," *The Journal of the Royal Aeronautical Society* LXXVI(1972).

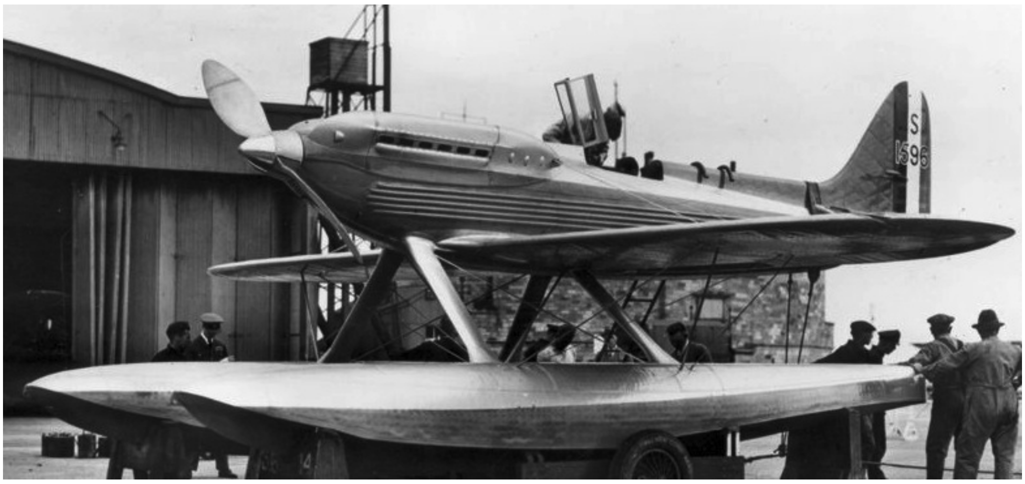

Figure 8 - Supermarine S. 6b (1931)

Supermarine designer R. J. Mitchell summed up progress from 1919 to 1929 in the Schneider Trophy:

> Quite a lot of information and experience is gained in the development of racing aircraft which is of undoubted value to the designer in all branches of aeronautical engineering and in many ways this has had a pronounced influence on the design of both military and civil types of aircraft.
>
> During the last ten years there has been an almost constant increase of speed in our racing types. To maintain this steady increase, very definite progress has been essential year by year. It has been necessary to increase the aerodynamic efficiency, and the power-to-weight ratios of our machines, to reduce the consumption, and the frontal areas of our engines; to devise new methods of construction; and to develop the use of new materials. The results obtained in the form of speed have been a direct and absolute indication of our progress in aeronautical development…Speed in the air must always be a measure of aerodynamic efficiency…[340]

The power output of racing aero-engines for this competition also increased at a rapid rate from around 260 horsepower with the Macchi *M. 7bis* of 1921[341] to around 2,350

[340] Reginald J. Mitchell, "Racing Seaplanes and their Influence on Design," *Aeronautical Engineering Supplement, The Aeroplane* (1929).
[341] Enzo Angelucci and Paolo Matricardi, *World Aircraft, 1918-1935* (Milan: BCA, 1977). p. 149.

horsepower of the Supermarine *S. 6b* in 1931.[342] It is interesting to note that the output of 2,350 horsepower would not begin to be approached by engines used in RAF fighter aircraft until well into the Second World War.[343]

The changes experienced by British Schneider Trophy aircraft were the result of increasing the power output of aero-engines and extensive work carried out by the National Physics Laboratory and the Royal Aeronautical Establishment. The most radical changes came after the major involvement of the State in terms of funding and research, not to mention the use of pilots from the Royal Air Force's high-speed flight.

BRIEF OVERVIEW OF THE CONTEST

The contest was initiated in 1913 by Frenchman Jacques Schneider who believed that flying boats would be of great importance in the future and thus started the competition as a means to encourage and foster development of this type of aircraft.[344] The inaugural contest in 1913 was won by the French SPAD *Deperdussin Monocoque*[345] seaplane at an average speed of 45.71 miles-per-hour. The *Monocoque* was revolutionary at the time for several reasons; it was the first aircraft to exceed 100 miles-per-hour (achieved after the Schneider win), it made use of a single shell design, and was monoplane in configuration.

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342 *Ibid.,* p. 85

343 Thetford, *Aircraft of the R.A.F.*: p. 484. Bill Gunston, *World Encyclopedia of Aero Engines - From the Pioneers to the Present Day*, Fifth ed. (Sutton Publishing, 2006). p. 36, 190.

344 Anon., "The Schneider Cup Seaplane Race," *Flight* XVII, no. 39 (1925): p. 609.

345 A monocoque (single shell) airframe is one that relies on its outer surface for support rather than internal bracings. Also, SPAD is the short-hand name for Société Pour L'Aviation et ses Dérivés, a major French aircraft manufacturer between 1911 and 1921.

Despite such progressive design elements, the trend at the time was moving towards the physically stronger biplane, which resulted in few private orders for the aircraft.[346] During the next contest in 1914 the speed of 45 miles-per-hour was almost doubled by the British entry, the Sopwith *Tabloid*, at 86.83 miles-per-hour. The contest was postponed at the outbreak of the First World War and resumed again in 1920 with Italy as the sole competitor, and unsurprisingly the winner. Italy won again in 1921 with the Macchi *M. 7bis* pictured above and a speed of 117.85 miles-per-hour, the other competitors failed to start the race. For the 1922 race, Britain submitted the first Supermarine entry, the *Sea Lion*, a biplane of similar construction and appearance to the Macchi *M. 7bis*, and won the competition that year attaining a speed of 145.67 miles-per-hour.[347]

Entries from the United States won both the 1923 and 1925 contests at 177.27 miles-per-hour and 232.57 miles-per-hour respectively. The British entry for the 1925 contest was the Supermarine *S. 4* monoplane. It was the first of Reginald Mitchell's monoplane racers designed for the Schneider Trophy, and the first monoplane to take part in the contest since the SPAD *Monocoque* of 1913. Unfortunately, due to a weakness in the wing design, the *S. 4* crashed during a trial run before the contest. In 1926 the Italians won yet again with the new Macchi *M.39* and a speed of 246.50 miles-per-hour. The *M.39* followed on from Mitchell's *S.4*, being an exceptionally clean monoplane design. The 1927 contest again revived Mitchell's interest in racing monoplanes, and Supermarine *S.5* won with a speed of 281.66 miles-per-hour. The *S.5* was a result of extensive research carried out at the National Physics Laboratory and the Royal Aircraft Establishment. It had an all-metal fuselage and was designed

[346] F. T. Jane, *Jane's All the World's Aircraft* (London1913). p. 89.
[347] Angelucci and Matricardi, *World Aircraft*: p. 72.

entirely around the engine – a powerful Napier *Lion VII B* which developed 876 horsepower.[348]

DECLINING GOVERNMENT SUPPORT

By 1929 Air Ministry enthusiasm for competing in the contest was failing. According to the Chief of the Air Staff (CAS) Lord Trenchard:

> I am frankly against this contest. I can see nothing of value in it. High speed machines will be developed by [the] Air Member for Supply and Research as and when necessary for research purposes, and they can race against the clock when it suits the Department, at a minimum of cost and of infinitely greater value.[349]

He concluded that:

> The contest is certainly not a good thing from the Service point of view; it is certainly a bad thing from the point of view of efficiency, and it is not good for the morale of the Air Force as a whole.[350]

Trenchard did not expand on his reasoning for suspecting a negative effect on the morale of the Air Force, but it is hard to imagine how this could be so given the position of ascendancy enjoyed at that time by RAF High-Speed Flight pilots in the competition. In the event, the Air Ministry did not entirely withdraw from supporting the 1929 race. They provided funding for the airframe but offered no money for a new aero-engine and also withdrew the offer for pilots of the High-Speed Flight. For the Air Staff it was a question of value for money, and the prevailing belief was that they would not get “value for the expenditure of effort (let alone the monetary cost)”.[351] This was not, however, the explanation given to the media and public. Suggested

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[348] *Ibid.,* p. 84
[349] NA AIR 2/1303 – Schneider Trophy Race: Future Policy after 1929 Race – CAS to Secretary of State for Air on the Schneider Trophy, 10th September 1929
[350] *Ibid.*
[351] NA AIR 2/1303 – Schneider Trophy Race: Future Policy after 1929 Race – AMSR to Secretary of State for Air, ‘Comments on CAS memo’, 10the September 1929

wording for notifying the newspaper media and the Air Attaches of participant nations, reflecting the continued popularity of the contest amongst the public, read as follows:

> The participation of the RAF in the last two contests has undoubtedly given a valuable stimulus to the development of British high-speed aircraft, but a position has now been reached when further development, so far as the RAF is concerned, can better take the form of normal research and experiment. Experience moreover has shown that competition between governments, backed by national resources, has tended progressively to give the contest a character that is not in accordance with its original intention.[352]

It is interesting that this decision was not made by the Air Ministry so much as it was the Government:

> …there was no feature of air policy in 1929, which has been more controversial or has aroused wider public interest than the Government's decision that in future, participation in the Schneider Trophy Contest should be left to private enterprise. The issue of policy involved was of sufficient magnitude to have been brought specially before the Cabinet, and the decision to discontinue Royal Air Force participation was not an Air Ministry decision, but a decision taken by the Government…Indeed, so great was the public interest in the matter that I should think that after the announcement of the Government's decision we had more Parliamentary questions on this topic than on any other single issue from all quarters of the House for some weeks.[353]

Eventually, the Air Ministry declined to offer any support at all for the 1931 contest:

> …although the entry of a Royal Air Force team was calculated to give a much needed impetus to the development of highspeed aircraft – and did so notably in the two latest contests – sufficient data have now been collected for practical development in this direction, and the

[352] NA AIR 2/1303 – Schneider Trophy Race: Future Policy after 1929 Race – Minute 21 to AMSR, 22nd October 1929
[353] NA AIR 2/1303 – Schneider Trophy Race: Future Policy after 1929 Race – Charles Bullock to Air Attaché to Berlin, 7th March 1930

large expenditure of public money involved by government participation is, therefore, no longer justifiable.[354]

Mervyn O'Gorman, superintendent of the Royal Aircraft Factory and head of the Royal Aeronautical Establishment took an entirely different view and cited the invaluable influence on civilian research work that came from competing in the contest:

> Government research workers will find themselves once more obliged to press their work forward for use by a given date…Such work is helped by the spirit of emulation and if side issues of more remote scientific interest are in some degree made subservient to the purpose of improving a very good aircraft, this is a good result…By this contest the Scientific workers are pressed to produce their results in a readily assimilable form, for the industry and then these results are tested in practice against the results of independent researchers in other countries, again a rare experience and valuable…Manufacturers and designers are by the urgency of their desire to win, pressed into the closest contact with research, therefore their practical problems are exposed in more detail to the research side than would normally be the case…[355]

However, the Air Ministry's reluctance to offer any funding for a new engine in 1929 was to prove highly significant as it led to a close relationship between Supermarine and Rolls-Royce (who provided their *'R'* type V-12 engine). In a letter to Air Commodore Holt of the Air Ministry, Air Commodore Chamier (a director at Supermarine) discussed the upcoming contest of 1931:

> Supermarine and Rolls-Royce have been discussing the possibility of defending the Schneider Trophy in the absence of any direct government entry. We set ourselves the task of obtaining an increased speed of 25 miles round the course, and for this purpose we decided that we should require 400 h.p. more from the Rolls-Royce 'R' engine. In order to obtain this horse

[354] NA AIR 19/126 – The Schneider Trophy Contest, 'Future Schneider Trophy Contests – Government's Decision not to Participate', 1929, p. 1.
[355] *Ibid.,* 'Plea for Government Support of the Schneider Cup Contest 1929' by Mervyn O'Gorman, 22nd November 1927, pp. 1-2

> power, which it is hoped could be got without appreciable increase of weight or dimensions, some 100 hours of development running would be required by Messrs. Rolls-Royce.[356]

The 1931 contest (and subsequent British outright victory) was made possible by a donation of £100,000 (roughly £4,500,000 today) from Lady Houston.[357] This money was to prove significant as the Air Ministry had denied the use of its pilots of the High-Speed Flight and insisted that the 1929 machine could not be used.[358] Curiously however, the Air Staff did acknowledge the importance of the Air Races for 'proving' the superiority of certain design features. Deputy Chief of the Air Staff (DCAS) considered that "the Schneider Trophy definitely proved the supremacy of the monoplane for pure performance".[359] AMSR Hugh Dowding (who would later become Air Chief Marshall in charge of Fighter Command) noted that:

> If for instance we take the history of our successful endeavour to win the Schneider Trophy, it may be said that the knowledge gained in the field of aircraft and engine design amply repaid the time and money spent on it up to a certain stage which I might put at the attainment of a speed of 300 m.p.h [for Service aircraft].[360]

What is interesting about Dowding's thoughts (from 1933) on the Schneider Trophy is that he regards the attainment of 300 miles-per-hour by Schneider racers to be the most useful outcome for RAF aircraft technology.[361] By the last meeting in 1931, however, the Supermarine *S. 6B* won the contest outright with a speed of 408

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[356] NA AIR 5/537 – Schneider Trophy, 1931 – A/C Chamier to A/C Holt on the 1931 Schneider Machine, 14th March 1930

[357] NA TS 28/207 – Lady Houston's Offer of £100,000 for a Schneider Entry. As the Air Ministry had funded the design and production of the airframe, they retained ownership after the contest.

[359] NA AIR 20/70 – Development of Fighter Planes, Jan. 1925 – Oct. 1940 – DCAS to DDOI, 'Service Personnel Ideas to Improve Fighters, 4th November 1932

[360] NA AIR 2/639 – World Record Flights: Policy on Future Participation – AMSR to CAS on Air Ministry policy of World Record Flights, 28th April 1933

[361] As the Schneider Trophy was mostly a contest of speed, other considerations such as a high rate of climb or low landing speed were of no importance.

m.p.h.[362] It is probable, therefore, that the speed of 400 miles-per-hour was of little real benefit to the RAF due to limitations on airframe design for the Air Force. Indeed, as Dowding put it:

> The increase in knowledge which we obtained by putting the speed up to 400 m.p.h. scarcely perhaps repaid the amount of time and energy diverted from other objects, although, of course, the moral effect of our victory was a very great asset to the prestige of the nation and to the prosperity of the industry.[363]

Dowding's comments were directly in opposition with those made by Trenchard above regarding the value of the Schneider Trophy. In essence, the Air Staff lost interest in the Schneider Trophy because the technologies in use for racing seaplanes could not, without great effort and expenditure, be immediately integrated into Service machines. Despite the great promise of the speeds attained by the Schneider machines, the feeling was that the contest had done its job in driving the extreme speeds which were required for international competition, but that it would be some significant time (which could be considered to be around ten years) before such speed could be achieved by Service aircraft.

Figure 9 - Supermarine Sea Lion II (1922)

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[362]Angelucci and Matricardi, *World Aircraft*, pp. 83-85

[363] NA AIR 2/639 – World Record Flights: Policy on Future Participation – AMSR to CAS on Air Ministry policy of World Record Flights, 28th April 1933

The changing nature of the contest certainly provided the scope for radical change in Schneider Trophy technology; in making money, time at the National Physics Laboratory and so on available, designers had the opportunity to perfect their aircraft as far as possible. The most straightforward way to illustrate this is to look at the designs of Supermarine which were involved in the competition.

Their involvement began in 1922 with the *Sea Lion II* (Fig. 3). It was a flying boat rather than a seaplane, of biplane configuration and with a 'pusher' style engine and propeller. As can be seen there is very little in the way of streamlining apart from the hull. There was no effort to house the engine in an aerodynamic casing, or to streamline the struts and wires between the wings. Nevertheless, it won the 1922 contest at an average speed of 145.67 miles-per-hour. As mentioned above, the United States won the 1923 contest with the Curtiss *CR-3* seaplane and also claimed second place with another *CR-3* while the Supermarine entry was relegated to third place. Supermarine had taken the *Sea Lion II* and given it a new engine taking it from 450 horsepower to 550.

Figure 10 - Curtiss CR-3 (1923)

The American *CR-3* made use of an aerodynamic cowling for the engine and streamlining of the floats, wings, braces and struts is evident. While still retaining the biplane configuration the *CR-3* was possessed of a much cleaner aerodynamic design than the *Sea Lion III*. Furthermore, the *CR-3* made use of a new type of engine technology, the wet-sleeve monobloc *D 12*. It was light and possessed of a very small frontal area allowing for further streamlining behind the engine.[364]

Figure 11 - Sea Lion III (1923)

Fig. 5 shows the slightly remodelled hull of the *Sea Lion III,* and an attempt to streamline the engine with a cowling of some sort. Despite these changes, the Supermarine entry came in 20 miles per hour slower than the *CR-3*. The failure of the *Sea Lion III* marked the end of the racing flying boat at Supermarine and convinced chief designer R. J. Mitchell that a radical solution would be required to dislodge the American racing biplanes.[365]

> Following the 1923 Schneider Contest, the next race in 1924 had never been far from Mitchell's mind. In June 1924 the Air Ministry ordered two experimental racing aircraft; a flying boat from Supermarine and a seaplane from the Gloster firm. Although Mitchell had

[364] Anon, "The 470 h.p. Curtiss D.12 Engine," *Flight* Vol. XVI, No. 17(1924).
[365] Mitchell, *Schooldays to Spitfire*: p. 53.

lost faith in the flying boats as a racing machine, he did design one powered by a Rolls-Royce Condor engine. Difficulties occurred during construction and the design, which was to have been called the Sea Urchin, was abandoned. Mitchell had a good eye for the right design and he knew that this one was wrong. He was convinced that a seaplane was needed to challenge the Americans.[366]

By 1925 Mitchell had abandoned the flying boat in favour of the seaplane. His response to the challenge presented by the new American Curtiss types was even more radical than the choice of Curtiss to switch to seaplanes. Mitchell opted for a cantilever monoplane seaplane design:

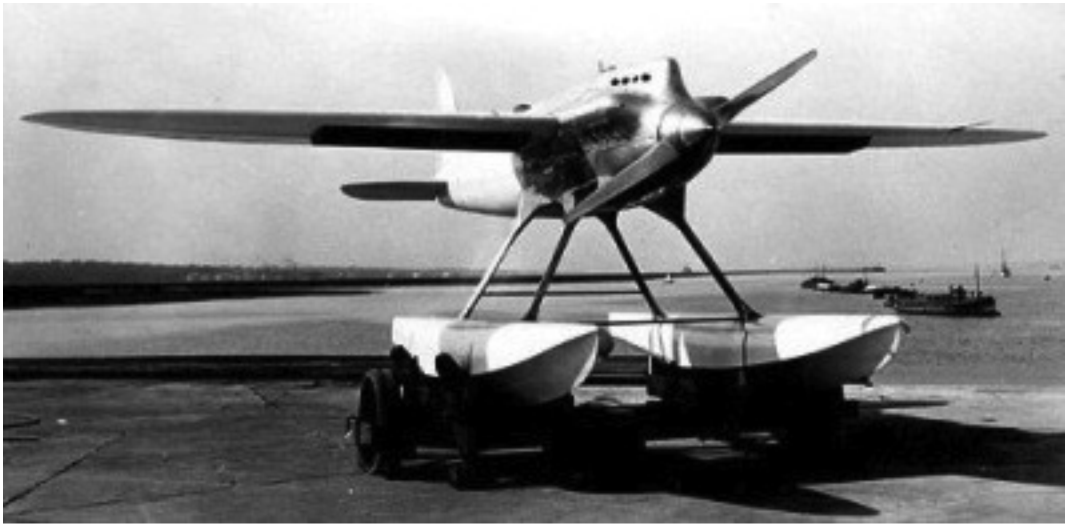

Figure 12 - Supermarine S. 4 (1925)

The British aeronautical press were surprised and fascinated by the new machine:

> The Supermarine-Napier S.4 is an exceptionally fine piece of work from every point of view, and at first sight one cannot help feeling a certain amount of surprise that a British designer has had sufficient imagination to produce such a machine. Perhaps one may describe the Supermarine-Napier S.4 as having the appearance of having been designed in an inspired moment, but having all that is considered best in British construction incorporated in its details.
>
> That the design is bold, no one will deny, and we think the greatest credit is due to Mr. R. J. Mitchell, chief designer of the Supermarine Aviation Works, for his courage in

366 Richard Riding, "The Sparrow," *Aeroplane Monthly* 13, no. 498 (1985).

> breaking away from stereotyped methods and striking out on entirely novel lines. When it is remembered that Mr. Mitchell has hitherto almost exclusively devoted his attention to the flying-boat biplane, it is little short of astonishing that he should have been able so entirely to break away from the types with which he has been so intimately connected for the past seven or eight years, and not only abandon the flying-boat type in favour of the twin-float arrangement, but actually change from the braced-biplane structure to the pure cantilever wing of the S.4[367]

The *S.4* utilised several uncommon methods and features in its design such as: stressed skin on the single-piece wing, a plywood skin covered fuselage, aluminium cowling for the engine bay and radiators mounted on the underside of the wing. It also utilised the Fairey Reed-type propeller.[ref] Some problems with the *S.4* were noted after the test flight, poor visibility was one, the other, more worrying problem was a vibration detected in the wing which, it was considered, might prove problematic given the two sharp turns often included in Schneider races.[ref] Given the impressive speed achieved by the *S.4,* however, it was decided that it would be entered into that year's contest.

The *S.4* crashed on the first turn of the race and the pilot Henri Biard believed the crash was due to wing flutter. However, experts believed it was more a case of a design far in advance of current aerodynamic theory.[ref] Mitchell wrote only a handful of papers discussing the development of his Schneider racing machines. However, he discussed the development of the *S. 5* at length in ARC Reports and Memoranda No. 1300. A close look at this paper will give a very good idea as to how this particular development process was conducted. Mitchell considered that:

> It was obvious that private enterprise could not shoulder the burden of the next contest [1926]…the problems which were faced by the S. 5 may be broadly classified as: a)

[367] Anon., "The Schneider Cup Seaplane Race," pp. 612-13.

Reduction of weight; b) Reduction of drag; c) Providing a satisfactory performance on the water.[368]

The first point he makes in this paper is to highlight the flaw in the unbraced wings of the *S. 4*, deciding that bracing the wings with wires to the floats and chassis offered a lighter and more rigid structure. He further points out that the structure weight of the *S. 5* was 36% compared with the 45% of the *S. 4*. Interestingly, Supermarine determined that "the biplane type would offer a very small further reduction of structure weight, which would be outweighed by the increase in drag. The biplane, moreover, gives a worse field of view for the pilot".[369] In reducing the drag of the *S. 5*, Mitchell considered that the reduction in weight was indirectly responsible for "a considerable reduction in drag, inasmuch as the wing area, the size of the floats, and the length of the fuselage are all affected by the weight of the aircraft".[370]

One of the most important aspects to this story is the collaboration between Supermarine and the National Physical Laboratory:

> The story of Mitchell's subsequent S.5, S.6, and S.6B and their engine development has been told many times, but with too little emphasis on the many hours of wind-tunnel testing at NPL [National Physics Laboratory] which whittled away at the profile drag of these machines so that, for example, the fuselage of the S.5 had 29 per cent less drag than that of the near-perfect-*looking* S.4.[371]

Indeed, Mitchell lauded the efforts of the NPL in his paper citing an extensive programme of wind tunnel research and the hard work of the NPL staff "so that no effort was spared to get the resistance down to the minimum possible…".[372]

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368 Reginald J. Mitchell, "Design of the S. 5," *Aeronautical Research Committee* Reports and Memoranda No. 1300(1931): p. 296.
369 *Ibid.,* pp. 296-297.
370 *Ibid.*
371 Hassell, "Advances in Aerodynamics."
372 Mitchell, "Design of the S. 5."

The extensive programme of tests covered every aspect of the aircraft; model tests for pitch, roll and yaw moments, tests on component parts, tests to ascertain interference effects, tests on the struts and wires and 'special tests', for example the study of flow round air intakes and the calibration of air speed indicators.[373] The following table[374] illustrates the reductions in drag achieved by these tests:

§	S. 4 Fuselage	S. 5 Fuselage	S. 4. Floats	S. 5 Floats	Airship Form	RAF 30 Section
Resistance in lb. at 100ft per sec.	9.3	6.6	5.0	4.43	-	-
Max. cross sectional area sq. ft.	8.46	5.18	3.70	3.19	-	-
Surface area sq. ft.	197	136	98.6	88	-	-
Resistance per. sq. ft. of cross sectional area in lb	1.1	1.27	1.35	1.39	0.9	0.94
Resistance per sq. ft. of surface area	.047	.0485	.0505	.0504	.034	.058

Mitchell notes in his paper that:

> …while the actual drag in each case is considerably reduced, it is only by reduction of the frontal area that this is achieved. The drag coefficient, expressed in terms of the frontal area, is greater on the S. 5 than on the S. 4 both for wings and floats. The coefficients in terms of

[373] *Ibid.*
[374] *Ibid.*, p. 298

surface area are more nearly equal, suggesting that further decreases of frontal area will only pay if the surface area is also reduced.[375]

The work carried out with the NPL paid great dividends in terms of increasing the understanding of aerodynamics as applied to Mitchell's racing aircraft. Some of the discoveries provided startling results, as in the case of the alignment of struts. It was found that a variation in strut angle of five degrees (yaw) increased the drag around the strut by approximately 25%. Furthermore, it was originally planned to use wires of a particular streamline section in place of the more usual lenticular form. Tests of the proposed streamlined section showed it to have more drag that the lenticular form by approximately 50% at 70 ft. per second.[376] Also, "among the improvements which the wind tunnel study confirmed was the advantage gained by using a wing radiator with a flat, instead of corrugated external surface". The following table[377] gives comparative figures for the types of radiator:

§	*Standard Hexagonal 10x120mm*	*Long Tube Hexagonal 10x360*	*S. 5*	*Externally Corrugated*
Weight of radiator per h.p. dissipated at 90 m.p.h.	*100*	*179*	*415*	*280*
Drag of radiator per h.p. dissipated at 90 m.p.h.	*100*	*76*	*0*	*14*
h.p. dissipated per unit cooling surface at 90 m.p.h.	*100*	*58*	*66*	*50*

[375] *Ibid.*
[376] *Ibid.,* p. 299
[377] *Ibid.*

Mitchell ends his paper by speculating on the future of racing aircraft in particular and aircraft in general:

> Racing aircraft have now reached a stage when improvement is only possible by giving detailed attention to the fundamental problems involved…*While these efforts [for the S. 5] resulted in a success which was gratifying, their real value lies in the experience gained, which is applicable not only to further racing aircraft, but no less to slower and less spectacular machines…*
>
> …Having reached a certain stage in development it is always interesting and sometimes helpful to indulge in a few surmises as to how further speed is to be attained. During the last six years an average increase of 30 m.p.h. per year has been accomplished…. The question as to how long this progress will be maintained is a very open one. Our machines are gradually becoming nearer to pure streamline form, and the nearer they become the harder it will be to obtain increases in speed. Surface skin friction already accounts for between 60 and 70 per cent. of the resistance of our machines, so that the room for improvement in pure streamlining is not of a very large order. As reduction in resistance is easily the most fruitful source of improvement in speed, it is probable that a gradual falling off in these yearly increases will be experienced.[378]

The importance of developing aero-engines is something which Mitchell touched upon in another paper:

> Very extensive progress has been made in engine design. During the past few years the weight-per-horsepower of our racing engines has been reduced by 50%, and the frontal area per horsepower has been halved. A large proportion of this progress has been passed on to standard engines used in service and civil aircraft.
>
> It is quite safe to say that the engine used in this year's winning S. 6 machine in the Schneider Trophy Contest would have taken at least three times as long to produce under normal processes of development had it not been for the spur of international competition.

[378] *Ibid.,* p. 301 & 306 (My italics)

> There is little doubt that this intensive engine development will have a very pronounced effect on our aircraft during the next few years.[379]

Indeed, the influence of racing engine technology was at times profound, and led to many breakthroughs in the improvement of engines for general use. The Curtiss *D. 12* wet-sleeve monobloc, mentioned above, was both directly appropriated for use in a Service machine by Richard Fairey, under license, and represented a shift in the design of aero-engines. It's small size, frontal area and lightness made it ideal for a racing engine, the fuselage being more easily streamlined behind it.[380] While the racing version of the engine was tweaked in such a way as to increase its horsepower and radically shorten its life, the commercial version provides an ideal example of how such engines with such racing pedigree could be adopted successfully into more standard aircraft.

A *D. 12* license was purchased by Richard Fairey in 1924 intended for use with his *Fox* high-speed bomber which was, incidentally, faster than any RAF fighter of the time.[381] Fifty such examples were imported from the United States with the intention that Fairey would build further engines under the license but the Air Ministry did not want another engine manufacturer in the industry. The squadron of *Foxes* ordered for the RAF were re-engined with Rolls-Royce *Kestrel's*.[382]

The Schneider Trophy was a hugely significant aspect of inter-war aviation. It provided the perfect showcase for demonstrating the potential benefits of the metal monoplane in 1925. Although it was difficult to immediately bring the effects of such

379 Mitchell, "Racing Seaplanes and their Influence on Design."
380 Anon, "The 470 h.p. Curtiss D.12 Engine," p. 233.
381 C. R. Fairey, "The Future of Aeroplane Design for the Services," *Royal United Service Institution Journal* 76(1931). Sinnott, *The R.A.F. and Aircraft Design*: p. 56. Thetford, *Aircraft of the R.A.F.*: p. 241. Peter Lewis, *The British Bomber since 1914* (London: Putnam, 1967). pp. 144-47.
382 Gunston, *World Encyclopedia of Aero-Engines*: p. 71.

high-level research and development to bear on military aircraft the process of R&D for the Schneider Trophy had profound effects on both the industry and the Air Ministry well into the 1930s. The relationships that arose from working on Schneider aircraft, most notably between Supermarine and Rolls-Royce, would prove to be an important part of the development of future fighters.[383]

[383] It is interesting to note that the relationship between Supermarine and Rolls-Royce was so strong that Rolls-Royce gifted a *Phantom* to Mitchell after the *S 6* success.

CHAPTER FOUR: 1931-1936

AIR STAFF PLANNING AND TECHNICAL DEVELOPMENT IN PEACETIME (II)

The years 1929-1936 represented a major shift in Air Ministry policy towards both aircraft design and procurement. By 1936, the Air Ministry would have moved entirely away from the conventional biplane of the 1920s for almost all of its operational roles. Designers, too, would have embraced the low-wing monoplane as the new design paradigm. But before moving on to one of the most fundamental shifts in aircraft design it is necessary to examine the changing nature of the Air Ministry, the shifting focus of research and the way in which aircraft for the Royal Air Force were procured. All of these themes will be picked up in the second section of this chapter and used to describe the evolution of fighter aircraft between 1929 and 1936.

In 1931 the Aircraft Supply Committee (ASC) reported that:

> The present year finds the Royal Air Force with four years' experience of war on an intensive scale and the accumulated experience of 12 years' development in peace. It has passed through the difficult period of changing policies, wartime types of aircraft and an impoverished aircraft industry and has approached a more ordered though not less active phase of its development…At the outset it can be accepted frankly that the design, manufacture and inspection of British aircraft for Service and commercial use have attained a world-wide reputation for excellence; and the result of the efforts made to that end are now being reaped in the form of foreign orders to the aircraft industry and in the supply to the Service of aircraft embodying all those qualities which only exhaustive research, experiment and development can secure.[384]

Exports of British aircraft and orders to the industry increased steadily throughout the 1920s[385] but the real value to the industry lay in the sale of licenses for foreign companies to build replicas. The Aircraft Supply Committee report continued by pointing out:

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[384] NA AIR 2/1322 – Aircraft Supply Committee Report, 1931, Appendix V, p. 38
[385] Edgerton, *England and the Aeroplane*: p. 24; ibid.

> …that the standard of excellence attained in the field of design, manufacture and supply can only be secured to the future by the periodic overhaul of the existing organisation, the abandonment of its obsolete parts and the investigation of new methods… Steady and continuous progress can only be assured by the adoption of means justified equally by past experience and future expectation.[386]

In the previous chapter we saw how the Air Ministry searched throughout the 1925-1929 period for a systematic programme of development and procurement for the Royal Air Force. It was shown that many of the problems experienced in the design and production of military aircraft were caused by (or at least blamed upon) the 'changes the designer is called upon to make in the course of construction'.[387]

Following Air Commodore Charlton's survey of the aircraft industry in 1926, the Air Staff defined three periods in the life of an aircraft: experimental, development, and production. They decided that following Charlton's report that modifications should not be made while an aircraft is in the production stage.[388]

The 'development year' was proposed as a way of evaluating an aircraft through operation by a Service squadron which was supposed to offer a deeper analysis of the aircraft than the standard RAE tests at Martlesham:

> …during the first year of its existence, a new type will be employed in one squadron only. The object of this "development" year is that the machine can be thoroughly tested out so that any defects can be discovered, necessary modifications prepared, and alterations to the drawings made before production orders are places. It also affords an opportunity of not proceeding with a type should it turn out unsatisfactory.[389]

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386 *Ibid.*

387 NA AIR 5/1368 – Air Commodore Charlton's Report: Survey of the Aircraft Industry and Allied Trades (1924-1925). Note: The report remarked on the bad effects on production and cost caused by modifications being applied to machines in the course of production.

388 NA AIR 20/68 – Aircraft Development Programme, F.O. 1 to CAS, 31st December 1929

389 NA AIR 20/68 – F.O. 1 Welsh to CAS, February 1930, p. 1

It appears, however, that these changes were not adhered to, as related by Wing Commander Welsh (Flying Operations 1, the officer responsible for operational requirements):

> This procedure has not been rigidly adhered to owing to the urgent necessity, during the last few years, of replacing types of war time design and certain other that have proved unsatisfactory…my conception of the procedure is that it was not intended that modifications should actually be embodied in the machines during the development year (except of course those affecting the safety of flying) but that they should be considered altogether at the end of that time…In practice, however, this has not proved to be the case, and opportunity appears to have been taken of the development period to embody in the machines any modification, large or small, which is thought at the time to be necessary.[390]

Welsh points out that given the widespread nature of the faults requiring correction over a number of aircraft (he cites the Bristol *Bulldog* as being recalled to the manufacturer three times with thirty-five modifications, and the Boulton-Paul *Sidestrand* requiring twenty-five modifications as examples) this indicated a lack of "attention to detail or faulty design on the part of the constructors".[391]

Welsh had noted a couple of months earlier, however, that it was also difficult to apply this policy of non-interference given the "unstable state of aircraft design, and particularly to the change-over from wooden to metal construction and the early days of metal construction".[392]

It would be a mistake to assume that Air Ministry specifications, the way they were formulated and the factors conditioning operational requirements remained the same throughout the inter-war period. During the First World War aircraft designed and manufactured for the Admiralty and the War Office experienced two entirely

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390 *Ibid.*
391 *Ibid.*, pp. 1-2
392 NA AIR 20/68 – F.O 1 to CAS, 31st December 1929

different systems of development. The Admiralty's method was to depend largely upon the private enterprise of aircraft manufacturers, add something to the requirements of existing aircraft and try again.[393] The Admiralty's 'specification' for want of a better term, was minimal.

For example, a specification to Short Brothers Plc. in 1914 specified buoyancy of the floats, a metal-covered propeller, fuel for five hours, wireless telegraphy and flying stresses. Everything else was to be left to the designer. Furthermore, it appears from Richard Fairey's account that the Admiralty system was far more collaborative, with the development of an aircraft depending upon the personal liaisons between the heads of the Air Department and the firms.[394]

> This policy on the part of the Admiralty certainly gave great stimulus to the industry and, thanks to their support of private enterprise, there were available effective designs of machines at the outbreak of war. The three or four firms who formed the nucleus of the industry and played so great a part in the war productions owed their existence very…largely to the Air Department of the Admiralty.[395]

By contrast the War Office 'took exactly the opposite line'[396] and concentrated on the design of aircraft entirely on its own at the Royal Aircraft Factory at Farnborough. All design work for the Army was to be carried out there and machines would be built from official drawings by industry.[397] This system failed due to its inflexibility, and inability to cope with the rapid changes that often needed to be made to aircraft and the War Office system could not cope.[398] The point Fairey made in his paper to the Royal United Services Institution was that during the First World War nothing "could

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393 Fairey, "The Future of Aeroplane Design for the Services," p. 564.
394 Ibid., p. 565.
395 Ibid.
396 Ibid.
397 Fairey, "The Future of Aeroplane Design for the Services."
398 Ibid.

be allowed to stand in the way of the application of new ideas which would give a quick return in performance". There was urgency, a need for flexibility and there was no time "for laboriously prepared specifications".[399]

Following the First World War the newly formed Air Ministry and RAF were left with yet another set of unknowns to deal with. Before the War there was very little in the way of an organised aircraft manufacturing industry or of a government knowledgeable enough to use it. The War had rapidly changed that landscape and a system, or systems, of design, development and manufacture had emerged through the changing nature of aerial warfare and an ever-increasing appreciation of the role of aircraft in warfare. Once the First World War ended a new role had to be found for the RAF and new systems of aircraft procurement had to be developed. Malcolm Smith has noted that "the two world wars lend the years in between a false historical perspective…British defence had its own peacetime problems very different from those faced or likely to be faced in a European war".[400]

For much of the 1920s the government "committed itself to parity with the largest air force within striking distance of the United Kingdom".[401] The whole system of defence procurement was in the grip of the 'ten year rule', and procurement for the RAF was in the grip Lord Trenchard's arbitrary ratio of two bombers for every fighter whilst the development of fighter aircraft took a back seat to the offensive 'morale' bombing doctrine.[402]

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[399] Ibid., p. 566.
[400] Smith, "Air Power and British Foreign Policy," pp. 154-55.
[401] Ibid., p. 156. NA AIR 8/67 – National and Imperial Defence Committee (1923) Reports and Papers, Conclusions of Cabinet Meeting, 20th June 1923
[402] Malcolm Smith, "A Matter of Faith': British Strategic Air Doctrine before 1939," *Journal of Contemporary History* 15, no. 3 (1980): p. 434. Meilinger, "Trenchard and "Morale Bombing"."

Richard Fairey considered that the period after the War saw a greater degree of inflexibility in aircraft design due to research and development policy now aiming at "greater reliability and range of usefulness of existing types" and that because of this "the official organization became, I think, less flexible, to the discouragement of new ideas".[403] Fairey believed that during the early years following the War the technical experience gained from it was concentrated "into somewhat rigid ideas about every item of equipment and construction, there was little or no allowance for improvement which might be possible by changes from accepted practice".[404] Furthermore, it was now possible to spend time preparing "elaborate" specifications with prescribed requirements affecting:

> …not only equipment but structure, engine installation, cooling systems, in fact nearly every detail of the machine. In the fixing of detail within such narrow limits the cumulative effect on a complete design was lost sight of. There was in fact little left for the designer to do but to arrange the lift and control surfaces.[405]

The specifications did relax around 1925 and by 1930 Fairey considered that "we now see a new type of specification which has produced some highly successful machines and which is a marked swing back from the highly restricted one of five years before".[406]

Specification F.7/30 and the Search for a Low Wing Monoplane

This section will examine perhaps the most significant turning point in the development of Royal Air Force fighter aircraft of the inter-war period. We have seen

[403] Fairey, "The Future of Aeroplane Design for the Services," p. 566.
[404] Ibid.
[405] Ibid.
[406] Ibid., p. 568.

that to some extent the development of military aircraft technology had stagnated during the 1920s. This is largely to do with the vast post-war surplus after 1918 and the Air Staff's adherence to the 'ten-year rule'. These factors had a remarkable knock-on effect in that there was very little urgency or need for radical changes to aircraft designed for the Air Force. For the Air Ministry there was a 'perceived need to keep a national aircraft design and manufacturing capability in being'[407] and that simply meant providing the industry (or rather, the chosen few within the industry) with enough work to keep them in business.

Central to this chapter is the development of fighter aircraft during the 1930s and of the specifications issued to the aircraft industry. There is a great deal of confusion in the literature, firstly about the details of specifications and their origins and also about the evolution of the first-line RAF fighters that would be used in the Second World War. This confusion is mostly down to a failure to understand the two distinct lines of RAF fighter development begun in the late 1920s. These distinct operational roles would continue into the 1930s and their influence was to be felt in every specification and in every design tendered to the Air Staff for evaluation.

The concept of the Aircraft Fighting Zone was begun in 1923 and the idea was to have fourteen of the seventeen fighter squadrons then in existence assigned to a particular defensive sector and:

> …disposed in such positions as to enable them to meet enemy aircraft in a prepared zone drawn round and parallel to the coast at a distance of approximately 30 miles…This zone is termed the Aircraft Fighting Zone.[408]

Aircraft used in the Fighting Zone were referred to as 'Zone Fighters' and because such aircraft were to be able to operate in day and night conditions, this necessarily

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[407] Sinnott, *The R.A.F. and Aircraft Design*: pp. 78-79.
[408] NA AIR 8/73 – Fighting Squadrons, 1923

meant a sacrifice in landing speed due to the difficulty of landing at night and a correspondingly lower top speed. Their main requirement was to be able to climb quickly to meet their patrol height. The 'interception' fighter on the other hand, operated only during the day and was to be used to catch up with and harass the faster enemy day bombers on their way to attack their targets and also on their way out. The primary requirement for this aircraft was speed. They needed to be fast to cover distances in a pursuit climb, and so performance and volume of fire was to be high at the cost of endurance and radio.[409]

In the formulation of specifications issued to firms the core elements of landing speed, top speed, rate of climb, manoeuvrability and volume of fire were shaped initially by the type of fighter it was to be. Thereafter a good deal of haggling would take place at the Air Ministry to finally get to a set of agreeable figures and requirements.

Throughout the 1920s Trenchard's grip on the Service and his generally conservative nature when it came to new technology left the industry with little motivation to go beyond what was asked for in the specifications. Indeed, when such instances of a designer doing so occurred, most notably with Richard Fairey and the Fairey *Fox* bomber, Trenchard's conservatism, his unwillingness to compromise and particularly his prejudice toward technologies he had not asked for, became apparent and such aircraft were rejected.

The Fairey *Fox* stands as an example of a highly successful technology that never reached its full potential in terms of Service use through beauracratic prejudice. The order placed by Trenchard for a squadron of *Foxes* (using the new wet sleeve engine) was designed to spur on Napier and Rolls-Royce and the development of their

[409] Sinnott, *The R.A.F. and Aircraft Design*: pp. 17-18, 61-62.

engine programmes. The *Foxes* that were ordered eventually had their engine's changed from the American *D. 12*-type to the Rolls-Royce *Kestrel.* Specification 12/26 was issued to firms looking for a replacement for the *Fox*, Richard Fairey was not given a copy of the specification until he protested to the Air Ministry. The Hawker *Hart* was chosen and the *Fox* designed for the new specification was ordered by foreign governments. Air Ministry prejudices against the *Fox* stemmed from the fact that firstly, it was not designed to an official specification, its fuel tanks were housed in the wings but most damningly it had an American engine. On consideration of the Fairey *Firefly* one Air Ministry official noted that he was "anxious to avoid a repetition of the Fairey *Fox* agitation".[410]

In his book *The Broken Wing*, David Divine gives a damning indictment of the Air Ministry up to 1930. Using the example of the *Fox* (discussed above) he condemns the Ministry thus:

> Its requirement procedures – the basic means of maintaining the qualitative standing of the RAF – are revealed as dramatically behind existing potential. Its committee system is exposed as obstructive and authoritarian. Its morality in relation to the aircraft industry is revealed as dubious. And its capacity for petty bureaucratic revenge is demonstrated as infinite…[Trenchard] left the Force for which he had fought so valiantly ill equipped not only in numbers…but in the quality of the machines for which it existed. He left the Air Ministry incompetent to obtain that quality.
>
> The Air Force that Sir John Salmond inherited [from Trenchard as Chief of the Air Staff] was cocooned in the era of the fixed undercarriage fabric-covered biplane. The Air Forces of other nations were already emerging from it.[411]

Divine's point is well taken, although largely overstated. The Fighter squadrons of the Air Force were equipped entirely with fabric-covered biplanes, and aircraft designed

[410] Taylor, *Fairey Aircraft since 1915*: pp. 133-34.
[411] Divine, *The Broken Wing*: p. 179.

for the Service only gained incremental improvements from type to type. Yet, the idea of 'quality' is a relative one and in discussing military aircraft the only real standard worth anything is that of the quality of aircraft in potential enemy air forces. Certainly, in 1930 there was little danger that British aircraft were of inferior quality relative to France or Germany. Furthermore, the RAF, industry and the Air Staff were only just emerging from the lean years of 1918-1924 and indeed from the 'ten year rule'. While there exists some exceptions to this rule, it should be remembered that from the time of initial discussion over operational requirements it would take between 5 ½ and 6 ½ years for the first machine to be delivered to the RAF.[412] It must be understood that the foundations upon which the industry operated throughout the 1920s were based largely upon these circumstances.

By 1929, however, things were changing rapidly. Trenchard had left the RAF and the Air Ministry, and new officers were coming in with new ideas about how air wars should be fought and about the technologies needed to fight such wars. Nowhere is this more readily apparent than in Air Ministry specification F.7/30. Wing Commander A. C. Maund argued in 1931:

> Past experience shows that, unless special action is taken, we shall inevitably be left to choose between certain tractor biplanes. This is because postwar progress has become concentrated on 'cleaning up' the stereotyped form of aircraft, and firms have accumulated a great deal of knowledge of this type. They can forecast closely what they can do, and there is a minimum of unknowns to be faced. They regard tractor biplanes as 'bread and butter entries'; novel types as 'highly speculative'. The inherent shortcomings of the normal tractor biplane are becoming increasingly evident, particularly with fighters, and so real progress in the future will depend more and more on novel types; but there can be no chance of developing these

[412] NA 2/1322 – ASC Report, 1931, Appendix VII, p. 1

unless experience is gained in adapting novel ideas to Service specifications, even if the Service cannot adopt first practical efforts in new directions.[413]

F.7/30 was formulated in an effort to produce a replacement 'zone fighter' for the, by then ageing, Bristol *Bulldog* (Fig. 1). Discussions began in 1929 with a view to issuing a specification by 1930-1931 and in the beginning the most important consideration was to improve the fighting view. The conversations taking place at the Air Ministry were no longer as conservative as they had been. For example, Flying Operations Officer (F.O.1) Welsh suggested that they "do not waste money building experimental machines on orthodox lines. We can always ask for replacements for existing types, taking into consideration the gradual development".[414] Furthermore, "we want a fighter with a pusher view".[415] A 'pusher view' is a view from the cockpit unobstructed by the upper wing of a tractor biplane.[416] Indeed, Welsh wanted to go further and for the purposes of experimentation and observation he recommended the AMSR purchase:

…one of the twin-engine Junkers K. 37 low wing monoplane day bombers, the particular advantages being the magnificent defensive arcs of firing to all guns and good view for defence. The Technical Branch are inclined to condemn the machine (not having flown it) on account of its landing speed.[417]

As we will see, the issue of landing speed was to have significant consequences for the F.7/30 specification. But in terms of improving the fighting view of RAF aircraft, Wing Commander A. C. Maund, taking over as F. O. 1 from Welsh in September 1930 echoed his predecessor's belief that:

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[413] NA AIR 2/2815 – Gauntlet and Gladiator Single-Seat Day and Night Fighter F.7/30, F.O. 1 to CAS, 29th June 1931
[414] NA AIR 20/68 – Aircraft Development Programme, F.O. 1 to DCAS, 11th October 1929, p. 1
[415] *Ibid.,* p. 2
[416] Sinnott, *The R.A.F. and Aircraft Design*: p. 77.
[417] NA AIR 20/68, *op. cit.*

> What we do want…is a much improved view in aircraft generally, but especially fighters. Frankly, it has always been a surprise to me that we have been satisfied even for day flying, much less for night work, with having large engines the size of cartwheels right in our faces and obstructing the most important view, namely, forwards and downwards. Last summer I tried the "Puss Moth" in which this shortcoming has been eliminated entirely. The view is better than with a twin-engined machine; in fact, it is as good as can be attained by pusher aircraft in essential directions. I am satisfied that the view from a "Puss Moth" would double the efficiency of any existing tractor biplane. The "Puss Moth" view makes flying entirely different and much less trying and fatiguing a business. In fact, I went up and found my way without discomfort or difficulty during the worst period of the Ascot Wednesday downpour.[418]

Figure 13 - deHavilland Puss Moth (1929)

Maund offered several suggestions for improving the view from fighter aircraft, in particular the use of twin engined fighters (necessarily placing the engines under the wings or at any rate out of the immediate view of the pilot), the ordinary tractor monoplane with an inverted engine (of which the *Puss Moth* is an example), the single engined pusher and "the tailless aeroplane. Actually the latter would meet operational requirements more satisfactorily than any of the others if only its development were pressed forward more vigorously".[419]

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[418] *Ibid.,* F. O. 1 to DCAS, 'New Aircraft Programme, 1931-1932, 6th October 1930, 'Twin Engined Night Fighter', p. 4

[419] *Ibid.,* p. 5

What we also can see within Maund's proposals is a far more practical approach to improving the fighter aircraft in a general sense and this approach is something that had been lacking before this point. Attempts to improve aircraft design had always been important to designers, but Maund was able in 1930 to highlight several key areas where improvement had been sorely lacking. It is very interesting to note that many of his proposals at first glance perhaps seem inconsequential. However, closer examination shows a careful thought process designed to maximise the effect of his suggested changes not only on the overall design of the aircraft but on improved functioning of the pilot and machine as a unit. For instance, he raises the issue of the armament carried on fighter aircraft at that time:

> Take for instance guns. We still use adapted land guns which were in use in aircraft during the [First World] War. The fire power of our aircraft is in no way increased. The guns are so primitive that they can only use specially selected ammunition and will only work by the negation of production requirements by individually made and hand fitted parts. They are so unreliable that they have to be fitted within reach of the pilot so that they can be repaired although aircraft carry less than a minute's supply of ammunition! Consequently their efficiency has to be limited still further by heavy, complicated and none too reliable and foolproof C.C. gear [interrupter gear]. What we want is a new gun, possibly of reduced weight, but sufficiently reliable for two minute's assured use without failure; so that it does not need to be to the hand of the pilot. It can then be outside the slipstream of the airscrew and C.C. gear could be eliminated. It would then be possible to use more than two in a fighter…[420]

This view of the armament carried by RAF fighters was echoed by Richard Fairey in his lecture to the RUSI in 1931: "It is a matter of the gravest astonishment to all aircraft designers that in this year 1931 a better machine-gun should not be forthcoming".[421]

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[420] *Ibid.*, p. 6
[421] Fairey, "The Future of Aeroplane Design for the Services," p. 570.

Maund also points out that the external windmills used to charge the dynamos that powered the navigation lamps, identification lamps and so on were a 'most inefficient form of drive…they were a justifiable improvisation in war, but are a proof of engineering ineptitude [when] perpetuated in peace'.[422] He highlights more examples with regard to mechanical starting of engines, flight clothing and so on and suggested that the Air Ministry should 'concentrate all new funds and efforts for at least one year entirely on these very serious shortcomings'.[423] Maund also wanted to see 'all-enclosed aircraft' though he conceded that "to design enclosed cockpits with the required view is not easy".[424]

Initially, then, by 1930 it had been broadly agreed that the forthcoming specification should place improved fighting view at the forefront and one option for this involved the use of a monoplane design: 'we would try to improve the view for fighting by definitely specifying a low winged monoplane'.[425] But there was much debate about the performance characteristics that the aircraft should have. The literature discussing F.7/30 reveals a startling number of inaccuracies which should be corrected here. The most common is that the specified speed was 250 mph, that monoplanes were not sought (indeed, that there was resistance to monoplanes), and that the Rolls-Royce *Goshawk* engine was specified.[426]

When the specification was issued in October 1931 it asked for a speed of not less than 195 mph and at no time during the debate that follows was a speed of more than

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[422] NA AIR 20/68 - F. O. 1 to DCAS, 'New Aircraft Programme, 1931-1932, 6th October 1930, 'Twin Engined Night Fighter', p. 7
[423] *Ibid.,* p. 9
[424] *Ibid.*, p. 11
[425] NA AIR 2/2815 – DCAS to CAS, 31st May 1930.
[426] An incorrect speed of 250 mph is given in Jackson, *Blackburn Aircraft since 1909*: p. 309. James, *Glostor Aircraft since 1917*: p. 171. A. Brew, *Boulton & Paul Aircraft since 1915* (London: Putnam, 1993). p. 321. F. K. Mason, *The British Fighter since 1912* (London: Putnam, 1992). p. 240. Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*. Scott, *Vickers*: p. 202.

215 mph considered. Furthermore, any approved British engine was permitted. As stated by Colin Sinnott "It was the Air Staff's intention to encourage the development of a new configuration for single-seat fighters, and in this they succeeded".[427] The problem regarding performance characteristics, specifically "the question of an acceptable compromise between maximum speed and landing speed was to delay the issue of the specification for many months".[428] This issue was problematic for many reasons. Primarily it was about gaining a worthwhile improvement in performance over the aircraft the specification was designed to replace, but it also involved a great deal of input from many within the Air Ministry.

The Bristol *Bulldog* had a top speed of around 176 mph[429] and initially it was thought that requesting a speed of 'not less than 195 mph' would be a sufficient improvement over the *Bulldog*. However, the Deputy Chief of the Air Staff (DCAS) believed that this did not represent a sufficient increase and called for a speed of 215 mph.[430] It was found that with the prescribed landing speed of 55 mph that nothing higher than 180 mph could be achieved as a top speed. Therefore the landing speed had to be raised and the DCAS suggested 62 mph, with revised performance estimates projecting a maximum speed of 190 mph.[431] Again, this was unacceptable to the DCAS who set a 200 mph top speed as the minimum to make the project worthwhile. Again, disagreement over the proposed landing speed delayed the specification with Maund reporting that:

427 Sinnott, *The R.A.F. and Aircraft Design*: p. 77.
428 *Ibid.,* p. 78
429 Angelucci and Matricardi, *World Aircraft*: p. 93, gives a speed of 174 mph. Though some have claimed around 178 mph such as Mason, *The British Fighter since 1912*.
430 NA AIR 2/2815 – CAS to DCAS & AMSR, 21st June 1930.
431 *Ibid.,* DDTD to DCAS, 29th August 1930.

[Director of Technical Development] proposed landing speeds which have gone up from 55 to 62 miles per hour. Air Staff have not agreed to more than 60 miles per hour. I suggest that, if we have erred at all, we have erred in te direction of being generous to D.T.D and that we should not allow 60 miles an hour to be exceeded.[432]

Around this time the newly appointed Air Member for Supply and Research (AMSR) Hugh Dowding entered the picture and stated that "I should like to go a little slow in the issue of the specification for a new Bulldog replacement if there is no strong objection".[433] For Maund this was welcome news. His belief was that in the meantime the £10,000 allotted for the *Bulldog* replacement work should be spent:

…in attaining technical progress which will make it possible…to build a machine to meet our requirements later. For instance, a large percentage of the disparity between what he [Director of Technical Development Holt] says is the maximum he can do and what we say is the minimum we can accept, could be bridged if the equipment carried were better.[434]

For the Director of Technical Development (DTD), on the other hand, this news was not welcome at all. He believed that the £10,000 would disappear from his budget if it wasn't spent, and further, that the resultant lack of design work would cause problems for certain firms.[435] Sinnott makes the point that such considerations on the part of the technical development staff show how factors such as "financial stringency, and the RAF's perceived need to keep a national aircraft design and manufacturing capability in being, could influence views on acceptable performance characteristics".[436]

Ultimately, it was agreed that a maximum speed of 200 mph and a landing speed of 60 mph should be sought, but that AMSR would not guarantee that the maximum could be achieved. The position regarding the *Bulldog* replacement

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432 NA AIR 20/68 – F.O.1 to DCAS, 7th October 1930, p. 2
433 NA AIR 2/2815 - AMSR to DTD, 10th September 1930.
434 NA AIR 20/68 – F.O.1 to DCAS, 7th October 1930, p. 3.
435 Sinnott, *The R.A.F. and Aircraft Design*: p. 79.
436 *Ibid.*

programme was summarised by the DCAS for the CAS in November 1930, it having been a year since discussion regarding the *Bulldog* replacement began. He recommended to the CAS that unless the minimum requirements could be guaranteed the replacement project should be, as recommended by Maund, delayed until research directed towards meeting these requirements could be conducted.[437] Dowding concurred and the CAS delayed the project for six months directing that action should be taken on the research issues raised by Maund, Newall and Dowding.

The researches demanded by the CAS were broadly those pointed out by Maund above, namely to improve the equipment carried by Service aircraft by aiming to reduce the weight and drag of items like the windmills used to drive the electric generators.[438] In May 1931 the six month postponement of F.7/30 ended and it is interesting to note that the CAS had shifted the priorities in terms of what was most desired for this specification. A good rate of climb was the first priority, a top speed of 200 mph was second, a good fighting view such as given by a low-wing monoplane or pusher third, and manoeuvrability was last on the list.[439] It is worth pointing out that the relegation of a good 'fighting view' in the order of priorities for F.7/30 does not actually reflect a change in Air Ministry thinking regarding these priorities but rather an "assumption that a low-wing monoplane would be specified".[440]

The specification, finally issued on the 1st October 1931, reflected these desires and the opening section should for once and for all dispel the myth that the Air Ministry was then opposed to low-wing monoplanes:

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437 NA AIR 2/2815 – DCAS to CAS, 10th November 1930.
438 NA AIR 2/615 – Policy regarding Internally Stowed Engine-Driven Aircraft Electrical and Wireless Generators to Replace Air Driven Generators – CAS to AMSR, 12 December 1930
439 NA AIR 2/2815 – CAS to AMSR, 18th May 1931
440 NA AIR 20/68 – F.O.1 to DCAS, 7th October 1930, p. 2

General Requirements

(a) The aircraft is to fulfil the duties of 'Single Seat Fighter' for day and night flying [a zone fighter]. A satisfactory fighting view is essential and designers should consider the advantages offered in this respect by low wing monoplane or pusher.

The main requirements for the aircraft are:

(i) Highest possible rate of climb

(ii) Highest possible speed at 15,000 ft

(iii) Fighting view

(iv) Manoeuvrability.[441]

Describing each of the prototypes submitted for testing would take too much space but it is important to look at some of the designs to appreciate the steps that some manufacturers were taking to move away from the fabric covered biplane. Eight firms tendered twelve proposals to meet the specification with six of them biplanes and six monoplanes. Four of these remained on paper and a prototype for these designs was never built. Perhaps the most advanced tender from a design point of view was the Bristol *Type 133* which embodied many progressive design elements such as a retractable undercarriage, cantilever wings, a stressed metal skin and an enclosed cockpit. It used the 640 h.p. Bristol *Mercury VIS. 2* air-cooled radial engine.

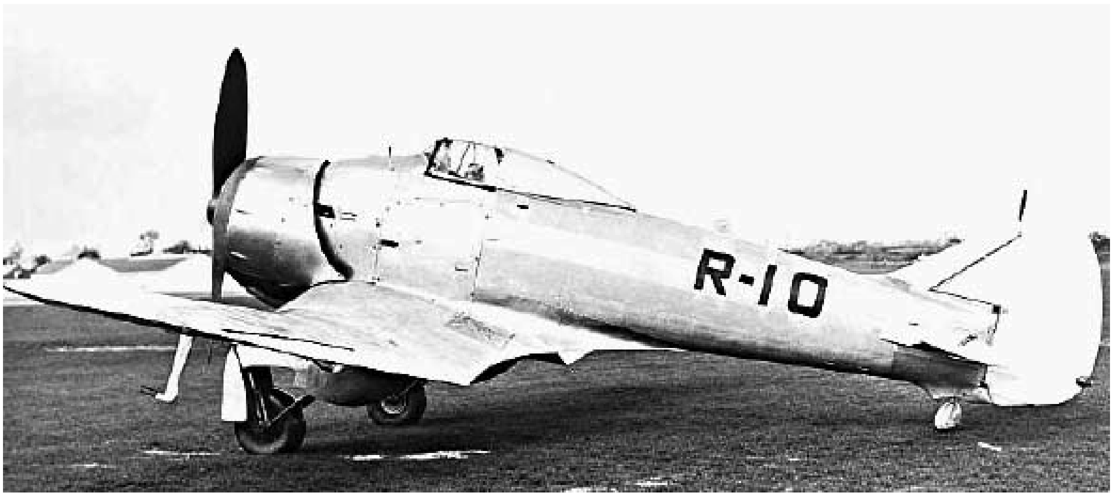

Figure 14 - Bristol Type 133 (1934)

[441] Price, *The Spitfire Story*: p. 27.

Unfortunately, despite highly promising test flights yielding a speed of roughly 260 mph at 15,000 ft, and a rate-of-climb of 2,200 ft./min.,[442] on 8th March 1935 the aircraft entered a flat spin from which the pilot could not recover and the prototype was lost.[443] Nevertheless, the *Type 133* stands as the best example of what the Air Ministry wanted from F.7/30. Modern, unorthodox and representing an attempt to push the boundaries of conventional design.

Bristol built one further entry, the *Type 123,* which was a biplane using the evaporative cooling *Goshawk*, and as with most aircraft that used this engine trouble was caused by the cooling system. Furthermore, test flights uncovered significant lateral instability and without a solution forthcoming it was decided to discontinue the *Type 123*. Performance tests revealed a top speed of 235 mph.[444]

Figure 15 - Bristol Type 123 (1934)

It will be remembered that Westlands were heavily engaged in the development of a tailless aircraft for the Service. As noted above, F.O. 1 Maund favoured this type over the monoplane, but getting it working as a practical proposition was proving difficult.

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[442] Lewis, *The British Bomber since 1914*: p. 232.
[443] Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*: p. 148.
[444] Ibid.

Accordingly, Maund's fear that firms might cling to the biplane types as 'bread and butter entries' was justified in this case. The Westland *P.V. 4* was originally conceived as a monoplane, but in order to meet the wing loading requirement and to meet the low landing speed stated in the specification the prototype was converted to a staggered biplane.[445]

Many of its design features reflected the specification, such as the enclosed cockpit with a pusher view, the pilot being seated forward of the upper wing. In a further effort to improve the fighting view the engine was mounted inside the fuselage around the centre of gravity, improving balance and manoeuvrability as well as allowing for a much cleaner nose.[446] It used the *Goshawk* and was one of very few aircraft to have minimal problems with it. However, the change from monoplane to biplane reduced the top speed significantly to around 147 mph at 13,000 ft. Amost 100 mph slower than the eventually winner of the F.7/30 contract.

Figure 16 - Westland P.V. IV (1934)

[445] Ibid., pp. 149-50.
[446] Lewis, *The British Fighter since 1912*: p. 227.

Another monoplane entry was the Supermarine *Type 224*. It has been suggested that "Both Vickers and Supermarine, with their F.7/30 tenders, broke away from the biplane in spite of the diehard official preference for it".[447] Once again we see the sort of mistake that has pervaded much of the aviation literature of this period and particularly with respect to fighter aircraft designed for the Royal Air Force. It was R J. Mitchell's experiences in the Schneider Trophy which had convinced him that for fighter aircraft, where speed was at a premium, the biplane had had its day. Despite this belief, however, the *Type 224* showed that while developing monoplane racers was one thing, adapting these principles to an RAF single-seat zone fighter was quite another.

The *Type 224* was an all-metal, low wing cantilever monoplane, with a fixed, trousered undercarriage and open cockpit. It made use of the troublesome *Goshawk* engine and indeed, a great many of its problems stemmed from the use of this engine. The belief was that the liquid cooled *Goshawk* would offer a significant increase in performance over air-cooled engines used in other tenders for F.7/30.[448] The problem with its use in the *Type 224* was the complicated way the pumping system had been installed into the aircraft. The *Goshawk* was cooled by pumping water "under pressure into the water jacket and was thereby prevented from boiling; the coolant was then released as steam into the radiator system where it condensed before being returned to the engine".[449]

[447] Ibid., p. 226.
[448] Sinnott, *The R.A.F. and Aircraft Design*: p. 84.
[449] Shelton, *Schneider Trophy to Spitfire*: p. 201.

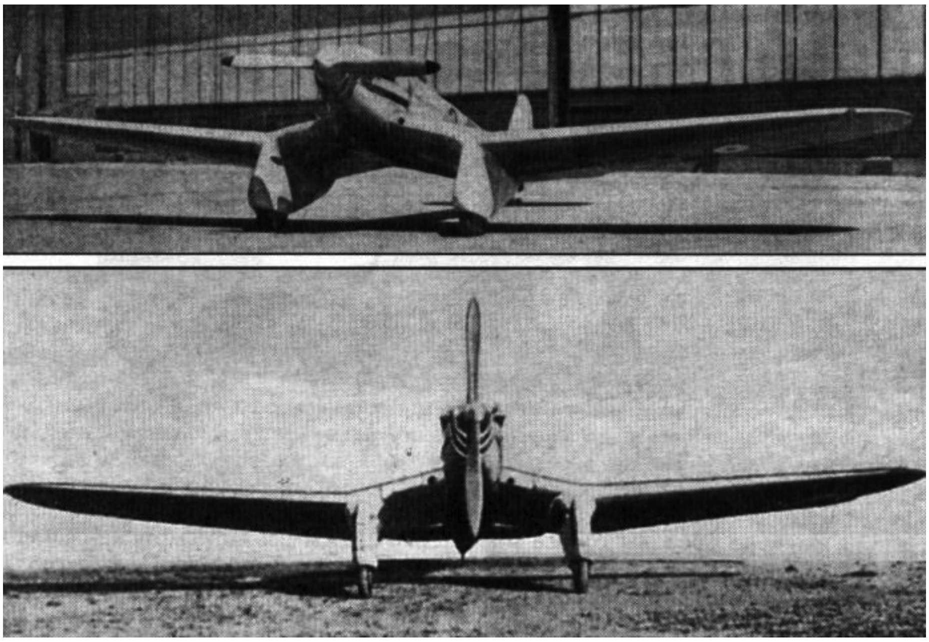

Figure 17 - Supermarine Type 224 (1934)

As Bill Gunston relates, the biggest problem with the *Goshawk* was "the impossibility of pumping condensate at near boiling point back from a condenser lower than the header tank, as it inevitably had to be in low-wing monoplanes".[450] So we can see from this example how the *Goshawk* was more effective in biplanes than monoplanes. Ernie Mansbridge who worked with Mitchell on the design of the fighter said that:

> We were a bit over-cautious with the wing and made it thicker than it need have been. We were still very concerned about possible [wing] flutter, having encountered that with the *S. 4* seaplane. With the *S. 5* and *S. 6* we had braced the wings, which made things easier. But the *Type 224* was to be an unbraced monoplane, and there were not many of those about at the time.[451]

Furthermore, the overall performance of the machine was relatively poor. The problems with the engine had consequences over and above simply overheating, although such problems were a direct result of this. For instance, "even if there was

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[450] Gunston, *World Encyclopedia of Aero-Engines*: p. 188.
[451] Price, *The Spitfire Story*: pp. 12-13.

no steam blockage at the pump the Type 224's Goshawk was liable to overheat during rapid climb to altitude".[452] Again Ernie Mansbridge said that:

> We always knew when he [test pilot Mutt Summers] got to 15,000 ft because a couple of bursts of steam would emerge form the wing tips. The climb was made at full power and relatively low airspeed, and when it reached that altitude the condenser was full and steam would start to trail back from the relief valves in the wing tips. Once that happened the pilot had to level off to give the engine time to cool down a little, before resuming the climb.[453]

Unfortunately for Supermarine, the *Type 224* did not offer any significant performance increase over its competitors which may have bought them some time to correct the flaws with the engine, or to find a suitable replacement engine. Its top speed was 238 mph, and it climbed to 15,000 ft in eight minutes.[454] As we will see, the eventual winner of F. 7/30 offered a better performance in both of these critical categories.

The winner of F.7/30 was the Gloster *Gladiator* and ironically it was precisely the type of machine that Maund and the rest of the Air Ministry wanted to move away from. It was a biplane, it used the air-cooled Bristol radial engine rather than the more troublesome *Goshawk*, had a fixed undercarriage and in very few ways represented the change in design that was sought from the specification. It had a covered cockpit but as can be seen in Fig. 8 attempts to improve the 'fighting view' were decidedly lacking. That being said, apart from the Bristol *Type 133* it had the best performance with a maximum speed of 242 mph and it could reach 15,000 ft in 6.5 minutes, 1.5 less than the Supermarine *Type 224*. As the DCAS reported to the CAS in 1931:

> Unfortunately, the Zone Single-Seater Fighter is the one class in which, for operational reasons, we can least contemplate any sacrifice in attainable performance. Throughout the

[452] Ibid., p. 14.
[453] Ibid.
[454] Ibid.

history of this class, there has never been produced a type which has given us adequate performance to meet the fastest contemporary Day Bombers.[455]

Figure 18 - Gloster Gladiator (1934)

The most important consideration of an improved fighting view when the *Bulldog* replacement was initially considered in 1929 was subsequently superseded by the need for performance. David Divine has argued that:

> In view of the records – and the subsequent accomplishments – of both these designers [Reginald Mitchell and Sydney Camm], it is apparent that the reason for the collapse was inherent in [the Air] Ministry's requirement. By its failure to demand even the generally acknowledged potential of the design teams, by its failure to demand the customary advancement of potential that is the primary purpose of experimental aircraft, it failed utterly to provide the necessary sense of urgency and enthusiasm for successful endeavour. It epitomised once again the weakness of the administrative machine of the Air Ministry: its timidity in progress, the poverty of its imagination, the stultification of its bureaucracy.[456]

The 'collapse' Divine is referring to is his judgement that the specification failed. This account of the 'failure' of F.7/30 to produce a fast, quality monoplane is highly misleading and entirely one sided. That the specification did not produce an Air Ministry contract for a metal monoplane, which is all that declinist authors such as

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[455] NA AIR 2/2815 – DCAS to CAS, September 1931

[456] Divine, *The Broken Wing*: p. 181.

Divine really want, is not disputed. The records and accomplishments that Divine refers to are Mitchell's successes and forward-thinking designs for the Schneider Trophy and Camm's continued successes at Hawker Aviation. But to preface the above statement with facts and figures from the Schneider Trophy racers is too simplistic. It implies that these designers, Camm, Mitchell and so on should have been quite simply able to replicate similar speeds in designing aircraft for the Royal Air Force.

Richard Fairey actually presented an exercise to the RUSI in which he took the Supermarine *S.6* and 'evolved it backwards' to show the quite serious technical limitations which would have to be applied in order to make it a functioning military fighter aircraft. The exercise shows that the *S. 6* top speed would drop from over 350 mph to 260 mph and reach 20,000 ft in 9 minutes.[457]

It is fair to state that the Ministry perhaps should have asked for more, but again we see the words 'backwards', 'weakness', and 'timidity' applied to the Air Ministry. It is simply not accurate. The specification called for a speed of '*not less than* 195 mph', the idea of course being that firms would attempt the maximum speed allowed by the landing speed restriction of 60 mph. It strongly suggested the low-wing monoplane as the form that tendered designs should take and the specification itself was delayed for six months while specific research was carried out to improve the streamlining of external apparatus required by the Air Ministry.

After the issue of F.7/30 the Air Staff continued to push aggressively for unorthodox fighter aircraft. The next section deals with the Air Ministry's pursuit of such aircraft in more detail, but it is worth noting again how labels such as

[457] Fairey, "The Future of Aeroplane Design for the Services," pp. 573-75.

'backwards' applied to the Air Staff are inaccurate. In a 1932 note to the DCAS, F.O. 1 Maund noted that:

> …for years past our technical experts have been following purely orthodox lines without variation…At least we tell the designer frankly what we want, show him how we want to get away from stereotyped tactics, and we leave it to him to make the best suggestions he can. It seems to me to be a waste of time for us or anyone else to try and do the designers job for them…As a matter of fact, we have ideas in Air Staff of a better form of fighter. But designers with their greater technical experience should be able to produce as good if not better alternatives.[458]

In addition to this statement from Maund, the DCAS also wished to factor in the expertise and operational experience in the formulation of fighter designs:

> I have agreed…to ask service personnel if they have any ideas which may lead to improving the general form of fighters as we now understand them. AMSR wishes to see if there are any ideas going in the Service which will produce an improved conception of fighters to comply more fully with operational requirements that is possible at present.[459]

A 1932 memo considering the choice of aircraft structures decided that "the arguments…point to the use of a low-wing cantilever monoplane for the utmost performance".[460] The move towards the metal monoplane was very much in full swing by 1934, and despite the winning design of F.7/30 being a biplane, the specification itself sparked something of a revolution in British military aircraft design, leading to the *Spitfire, Hurricane, Mosquito* and a host of others.

The *Gladiator* was built in significant numbers (around 750) and saw Service with the RAF and other air forces until it was retired in 1957, perhaps the most famous being the defence of Malta in 1940.

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[458] NA AIR 20/70 – Development of Fighter Planes, Jan. 1925 – October 1940, F.O. 1 to DCAS, 9th July 1932
[459] *Ibid.*, DCAS to DDOI through F.O. 1 – Service Personnel Ideas to Improve Fighters, 4th November 1932
[460] *Ibid.,* Memo – Choices for Aircraft Structures, 1931.

CHAPTER FIVE: 1934-1939

The years leading up to the Second World War from around 1936 were amongst the most stable in terms of fighter aircraft design. However, the years immediately preceding this period of stability saw some of the most visible and radical changes. The *Hurricane* and the *Spitfire* made their first flights in November 1935 and March 1936 respectively. The monoplane fighters which would feature so prominently in the Battle of Britain had arrived and were introduced to the Royal Air Force (RAF) in 1937. This period marked the beginnings of rearmament for the RAF, with the expansion of industry production towards capacities not seen since the First World War and the creation of the so-called 'shadow industry' (the construction of extra production facilities to compliment the existing floor space and plant of aircraft and engine firms). The rearmament period is significant in that it locked in the low-wing metal monoplane fighter design and committed ever-increasing resources to furnishing the RAF with the best, most 'modern' aircraft that could be acquired. This chapter will examine some of the later aspects of the inter-war story. The development of the *Spitfire* and *Hurricane* will be examined. Their development is a crucial part of the biplane to monoplane story.

Up to this point there had been a slow but steady development in aircraft design and technology. Such change was by turns incremental (the development of an existing paradigm) and revolutionary (the emergence of a new paradigm). The more revolutionary changes, such as the switch to all-metal construction were made possible by gradual innovation and growing support for a technology first pioneered some twelve years before the Air Ministry mandated metal construction for all future types in 1925. The wood/metal shift was significant, the reasons were largely practical and based on what seemed at the time to be sound premises. More gradual changes included the refining of aircraft aerodynamics and the strength of materials and structure.

Competitions like the Schneider Trophy (and others like the Gordon Bennett Cup) were able to demonstrate the potential advantages of monoplane designs for Service aircraft, in some instances almost a decade before the changes were to take place. The change to the monoplane itself was again driven by the Air Ministry, but sought much earlier than has been noted by most historians. The search for a low-wing monoplane fighter was one of the most significant steps during the inter-war years. While initially unsuccessful, specification F. 7/30 (issued in 1931) laid down a very clear instruction that low-wing monoplanes were preferable, but it would be a further six years before monoplane fighter aircraft entered service with the RAF.

BIPLANE OR MONOPLANE?

At this point it will be useful to quickly review and state clearly some points about both the biplane and monoplane and some of the factors involved in the change from the former to the latter. The Schneider Trophy had, in the words of the then Air Member for Supply and Research (AMSR) Hugh Dowding, 'proved' the superiority of the monoplane for pure performance. Dowding was talking largely about speed. The biplane (and indeed the triplane and quadruplane) were far more manoeuvrable at the lower speeds which were achieved given the enormous number of drag inducing components made necessary by their design.[461] As engine power increased and structure weight was reduced monoplanes became the more efficient design choice.

[461] Struts, bracing, wires, fixed undercarriages, lamps, RT gear and so on.

The Schneider Trophy 'proved' this to be true, to designers like Mitchell and Camm as well as the Air Staff, some ten years before the first monoplanes were to enter service with the RAF. However, Air Marshall Sir Ralph Sorley considered that:

> [The] low wing loading [of the biplane] had for years been regarded as the first essential for manoeuvre in attack. The monoplane was suspect on the grounds of strength during aerobatics and rigidity as a gun platform. Most fighter opinion favoured the biplane. But now the monoplane bomber began to show such an advantage in performance when fitted with retractable undercarriage, flaps, and, later, the variable-pitch propeller, that only another monoplane would be comparable. It seemed inevitable that, whatever the aerobatic advantages of the biplane, it would no longer catch the bomber, and so a monoplane it must be.[462]

In a talk given in 1924 on 'The Development of High Speed Aircraft', Major R. H. Mayo[463] told the Royal Aeronautical Society that due to achievements in France "it is obvious that the monoplane…has much to commend it...", and that "any method of increasing the maximum lift coefficient of a wing without increasing the drag at high speeds which may be perfected will, I think, tend to bring back the monoplane into favour for racing purposes".[464]

In 1929 in comments made to the Royal Aeronautical Society Air Vice-Marshall Sir William Sefton Brancker[465] noted that:

> [Sefton Brancker] was a gentleman who preferred monoplanes, but he was quite prepared to transfer his affections to biplanes if their superiority could be proved…The fact remained that

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[462] Air Marshall Sir Ralph Sorley, "Hurricane and Spitfire - Eight Guns for a Fighter," *The Times* 14th September 1957, p. 7.
[463] Mayo was a consulting engineer with the Air Ministry and RAeS.
[464] Major R. H. Mayo, "The Development of High Speed Aircraft," *Journal of the Royal Aeronautical Society* XXVIII, no. 159 (1924): pp. 173-74.
[465] Master-General of Personnel at the Air Ministry and Director of Civilian Aviation from 1922. Died in the R101 airship crash, October 1930.

> since the war all the great world records had been established by monoplanes – distance, duration, speed, and all the crossings of the Atlantic.[466]

The widespread adoption of the low-wing monoplane for fighter aircraft as it existed in 1939 had a lot to do with the wings themselves. Thickness, strength, position, bracing and a host of other factors influenced the change. Monoplanes were designed, built and were flown from the earliest days of flight. Indeed, the inaugural winner of the Schneider Trophy in 1913 was a monoplane. Early monoplane wings were externally braced, meaning that the wires attached to the wing were attached on the wing exterior and fastened to a central point or points on the fuselage, normally in front of and below the pilot.

Figure 19 - Bleriot Monoplane (1911)[467]

Strength and safety were two of the most important factors to early aircraft designers. The biplane suggested itself early on for precisely those reasons. The low-wing loading of the biplane meant that the forces acting on the wings were distributed

[466] W. S. Farren, "Monoplane or Biplane," *Journal of the Royal Aeronautical Society* XXXIII, no. Pt. II (1929): p. 523.
[467] Note the external bracing points above and below the pilot.

between the two, they could be braced with struts as well as wires and thus was altogether stronger than the monoplane.

The challenge for the cantilever wing was to be strong, light and efficient enough for adoption with fighter aircraft. Hugo Junkers had already had success with cantilever wings as early as 1917 with his *D 1* fighter. As technically impressive as it was at the time, being the first all-metal fighter in addition to having internally braced cantilever wings, it lacked manoeuvrability and was considered unsuitable for a first-line fighter.

Again, this pointed to drawbacks with early monoplanes, while in terms of pure performance (speed and rate-of-climb for example) there was no real difference between biplanes and monoplanes, in terms of manoeuvrability there was a great deal of difference. For fighter aircraft manoeuvrability was essential, and if no appreciable gain in performance could be achieved by using monoplanes and if in doing so some manoeuvrability was sacrificed, then there was no real incentive for designers to develop them.

Perhaps the most important development from a British point of view was the switch from biplane to monoplane configuration in the Schneider Trophy racers designed by Supermarine. As noted above, Mitchell's switch from biplane to monoplane proved the superiority of the monoplane for speed and performance, it also crucially increased the amount of work done in drag reduction. The first of his *S* series monoplane racers, the *S 4* crashed while conducting speed trials in Baltimore, apparently due to suspected wing flutter. The *S 4* was designed with fully cantilever internally braced wings. The next Supermarine effort, the *S 5* was designed with externally braced wings (due to fears over a repeat of the *S 4)*. The *S 5, S 6 and S 6b* won the contest outright in 1931.

Following this success, Mitchell's *Type 224* fighter designed to specification F. 7/30 was a monoplane, but an unsuccessful one. There were other problems (described in the previous chapter), including the engine, the uncovered cockpit and trouble getting beyond 15,000ft, but one of the biggest problems, and one that shows that the monoplane as a viable choice for fighter aircraft was not quite ready were the wings. By 1934 as the *Spitfire* and *Hurricane* were being designed, the cantilever wing was considered by both Sydney Camm and Reginald Mitchell as the only option if they were to pursue a truly high-speed fighter.

RETRACTABLE UNDERCARRIAGES

The undercarriage assemblies of early aircraft, those before around 1916 when speeds began approaching 150 miles-per-hour, produced only a very small portion of the drag created in the overall machine. As aircraft speeds increased throughout the War the undercarriage became a more obvious area for aerodynamic improvement and the struts used in the undercarriage were designed to be more streamlined, moving from "circular to elliptical or aerofoil cross sections".[468] Following the First World War in Britain there was a period of stagnation in many aspects of aircraft design where "caution and retrenchment" made "new ideas hard to sell".[469] Despite some efforts to remove the undercarriage from the airflow, and some effort to improve the fixed type (see Figs 2 and 3) there was little interest in developing them beyond First World War standards, that is to say, from the fixed assemblies of that period.

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468 C. Ellam, "Developments in Aircraft Landing Gear, 1900-1939," *Transactions of the Newcomen Society* 55(1983-1984): p. 49.
469 Ibid., p. 50.

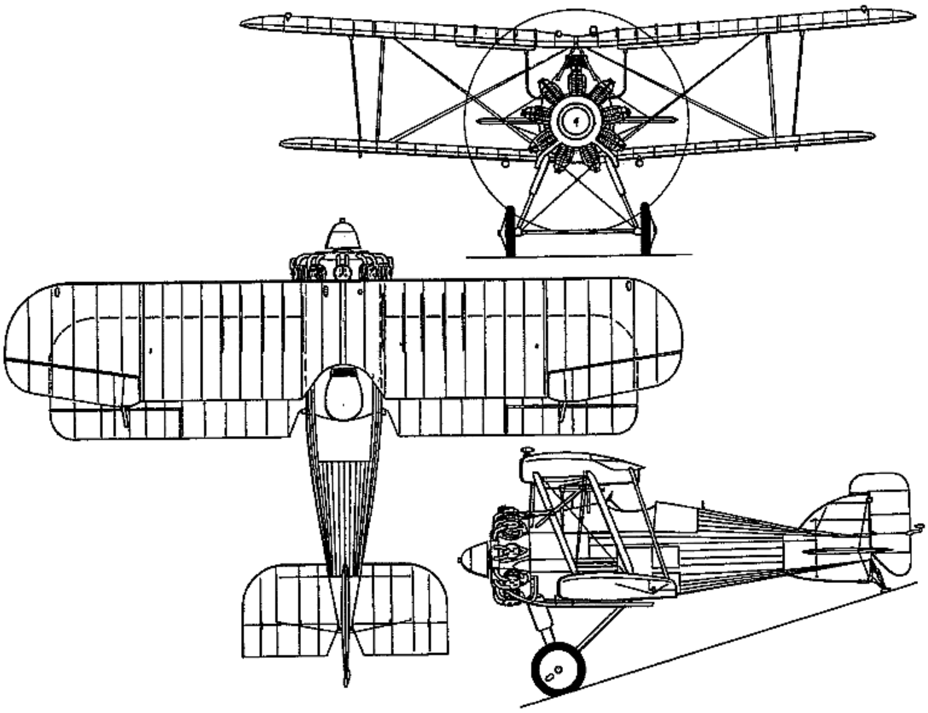

Figure 20 - Gloster Gamecock (1925) Schematic

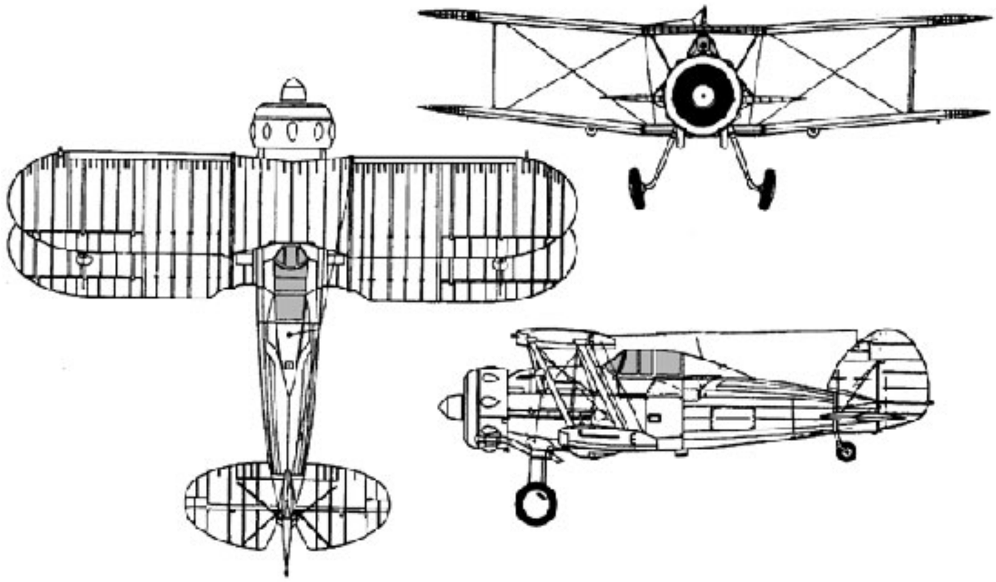

Figure 21 - Gloster Gladiator (1934) Schematic[470]

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[470] This 3-angle view of the *Gladiator* illustrates the last fixed undercarriage used by an RAF fighter before the adoption of the *Spitfire* and *Hurricane.* It is considerably less complex than the *Gamecock* landing gear of 1925. Comparing the two schematics, one can see other evidence of improvement over the nine years between them. The *Gladiator* has an enclosed cockpit, the fuselage is more streamlined, the radial engine is also far more streamlined. The improvements in the undercarriage should be obvious on sight, the *Gladiator* has no bracing or struts between the legs.

The development of a practical retracting undercarriage was a crucial development in the shift to the metal monoplane fighter. It was, however, the low-wing monoplane design that first and foremost allowed the widespread adoption of the retractable gear. Biplanes had been the mainstay of the Royal Air Force since its creation in 1918 until the first Service aircraft with retractable gears appeared in 1936 (the *Hurricane* and *Spitfire*). In understanding the perceived delay[471] in the adoption of retractable undercarriages it is important to realise that retracting the undercarriage was a complicated and costly process. Firstly, while it was possible to move the wheels into other parts of the aircraft, it was considered that to retract the landing gear into the wings was "obvious" and furthermore, it was thought that the lower wing of a biplane was far too thin to house the retracted wheels.[472] Thus, a low-wing monoplane was needed to make the retractable gear a realistic prospect in fighter aircraft. They had been used successfully in racing aircraft as early as 1920 in the Gordon-Bennett Cup[473] but their adoption in British fighter aircraft was curtailed by the RAF adherence to the biplane. Even still, the adoption of retractable gears in monoplanes was not straightforward. In 1930, experiments on the aerodynamic characteristics of undercarriages carried out on a Sperry *Messenger* found that removing the undercarriage from the model reduced the parasitic drag of the entire aircraft by one third.[474] George Dowty, a man famous for his development of, amongst many other things, undercarriages and hydraulic systems for retraction, noted that:

[471] *Flight* often noted the impatience of "ill-informed critics" regarding the adoption. For instance, Anon., "Retractable Undercarriages," *Flight* XXVI, no. 1330 (1934).
[472] Ibid.
[473] Mayo, "The Development of High Speed Aircraft," p. 174.
[474] G. H. Dowty, "Undercarriage Developments," *Journal of the Royal Aeronautical Society* XXXIV(1930): p. 170.

> The landing gear represents a large part of the total resistance [of the aircraft] and, because this unit is of no assistance to the aeroplane in flight, its weight and drag must be regarded as something of a dead loss.[475]

Dowty also considered that (in 1930) it was entirely usual to find mechanical complications, an increase in weight and a reduced efficiency in undercarriage operation and maintenance. In addition, the increased size of body needed to house a folded landing gear was "such that if there is any advantage it [was] so small that the additional cost [was] not warranted".[476] Finally, he offered some advice to designers:

> The only way to make improvements is to fix definitely in one's own mind what is unsatisfactory with present-day products…It may be that you cannot get them fixed all at once, but until you know and recognize that there is something wrong and that it needs to be improved, you have no centre point around which information and facts will crystallise.[477]

In 1931 as the RAF searched for a replacement fighter for the *Bulldog* the monoplane designs tendered to specification F.7/30 retained the fixed undercarriage synonymous with the biplane. Essentially, speeds were not yet high enough to justify the cost and difficulty of developing or using retractable gears.[478] Attempts at drag reduction on the standard undercarriage were limited to further streamlining of the components. Indeed, Supermarine's *Type 224* had a 'trousered' fixed undercarriage, where the struts were enclosed in streamlined casings.

In *The Retractable Airplane Landing Gear and the Northrop "Anomaly"*[479] Walter Vincenti talks about the adoption of retractable gear and of an example that bucked the trend. Vincenti points out that the adoption of the retractable gear was not,

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[475] Ibid.
[476] Ibid.
[477] Ibid., p. 183.
[478] Ellam, "Developments in Aircraft Landing Gear, 1900-1939," p. 50.
[479] Walter G. Vincenti, "The Retractable Airplane Landing Gear and the Northrop "Anomaly": Variation-Selection in the Shaping of Technology," *Technology and Culture* 35, no. 1 (1994).

as has often been suggested, reasoned, obvious or foresighted.[480] While there was a general adoption amongst the aircraft commonly pointed to as having led the way with retractable gears, Vincenti notes the example of John Northrop in the United States who stayed with the fixed, trousered landing gear in spite of a general movement away from this type. It is important to remember that retracting the landing gear actually worked years before its widespread adoption. Various designers tried it throughout the 1920s, but they were costly, complicated and difficult to maintain. It was simply not worth it, generally speaking. Vincenti points out that today, aircraft with speeds below 200 miles-per-hour almost exclusively use fixed undercarriages, those between 200-250 miles-per-hour use retractable gear and that aircraft of the 1930-1935 period were moving towards these kinds of speeds.[481]

The fact that aircraft speeds were increasing allowed for more consideration of retractable gears. As speeds increased the drag penalty of parasitic components like a fixed undercarriage became more and more serious. At 100 miles-per-hour, the effect was minimal, but approaching 250 miles-per-hour the effect became a good deal more significant.

Figure 22 - Airspeed Courier (1932)

[480] Ibid., p. 4.
[481] Ibid., p. 19.

Actually, the first British aircraft to lead the way in terms of being a low-wing monoplane with a retractable gear was the civil Airspeed *A.S. 5* (marketed as the *Courier*) in 1932. Its top speed was around 150 miles-per-hour and so it is difficult to imagine how a retractable gear was fully justified.

In May 1933 research presented to the Aeronautical Research Committee demonstrated that retraction of the landing gear could reduce the minimum drag of the complete aircraft by up to 50%.[482] That retraction of the landing gear could lessen the drag of a complete aircraft by such amounts was not disputed at the time - the tests carried out by the National Advisory Committee for Aeronautics in the United States, the Royal Aircraft Establishment in the UK and elsewhere showed this to be so. The problem was the additional weight, mechanical complication, design and being able to fit a retractable gear into an aircraft in the first place. In a letter from the Director of Scientific Research at the Air Ministry to the Aeronautical Research Committee, retractable gears were found not to "offer any advantage in view of the excess weight brought about not only by reason of the necessary mechanism but also on account of the strengthening of the wings about the wheel housing".[483]

Besides the quite radical reduction in drag offered by retractable mechanisms, one other benefit realised at this early stage was the effect of landing with no undercarriage. It was considered much safer to land with nothing than with a fixed gear which would make the aircraft 'nose over' at high speed.[484]

In 1935 the Royal Aircraft Establishment produced a report on defects of retractable undercarriages and it was prepared specifically for the information and

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[482] NA DSIR 23/3887 – Aeronautical Research Committee, 'The Aerodynamic Effect of a Retractable Landing Gear by Smith J. DeFrance (Summary of NACA Technical Note No. 456), 12th May 1933.
[483] NA 23/4026 – Stability and Control Sub-Committee (ARC), Aeroplanes with Retractable Undercarriages, DSR to ARC, 12th July 1933, p. 1
[484] Ibid., p. 2

guidance of designers. This shows both a commitment to improving retractable undercarriages and that there was enough functional examples to produce a report on 'troubles' that had thus far been experienced. Some of the problems were listed as follows:

1. One side of undercarriage remained locked in up position.
2. Unequal lowering of port and starboard wheels.
3. Damage due to sudden lowering of undercarriage.
4. Malfunctioning indicator lights – reporting fully lowered gear when the gear was not locked down.
5. Overwinding by pilot – no indication when the undercarriage was fully up.
6. Failure of hydraulic pump.[485]

It is interesting to note, however, that in 1936 Dowty stated that:

> Among the many problems of drag reduction engaging the critical attention of aircraft designers to-day, that parasitic appendix known as the undercarriage stands out, in more ways than one, as probably the most serious singe offender still challenging the ingenuity of the designing engineer in his unceasing quest for aerodynamic refinement.[486]

Dowty was mindful of the fact designers had been 'openly sceptical' of both the value and feasibility of retracting the undercarriage "at least in such a manner as to make it worthwhile". Dowty firmly believed that the emergence of the retractable landing gear allowed for much greater speeds in commercial aircraft. To support his claim he noted the "significant fact that what was once a novelty has now become an accepted operating feature of the world's leading airways, despite a great deal of prophetic cold

[485] NA AVIA 6/7065 – Royal Aircraft Establishment, 'Summary of Retractable Undercarriage Defects', August, 1935, pp. 2-4
[486] G. H. Dowty, "Retractable Undercarriages," *Journal of the Royal Aeronautical Society* XL, no. I (1936): p. 250.

water in the past".[487] By 1936 he considered that "suppression of the undercarriage "parasite" by retraction in flight [had] now passed into the realm of mechanical feasibility".[488]

Also by 1936 the majority of high-speed aircraft under development or construction, were initially projected with a retractable landing gear as standard.[489] As we will see later, this was a crucial shift in thinking on the part of designers. Finally, it was Dowty's opinion that "any aeronautical engineer wishing to keep abreast of his art, will accept them as part of his normal design technique".[490]

The Eight-Gun Adoption

Given that the primary function of a fighter is the destruction of enemy aircraft, the amount of firepower generated by a single machine is crucial. Fighter aircraft were developed to be, in essence, a gun platform. Generally, a biplane could only house guns in the fuselage and not in the wings[491], and this greatly limited the space available for armaments. The route from the single or double pilot operated machine gun of 1918 to the eight-gun monoplane fighter of 1939 is a complicated one, but it is an important aspect of the overall biplane to monoplane story.

Reaction to improvements in bomber aircraft were one major driver for the Air Staff in developing monoplane fighters. Considerations of repelling enemy fighter formations were largely secondary. For instance, somewhat controversially, Ralph

[487] Ibid., p. 291.
[488] Ibid., p. 292.
[489] Ibid.
[490] Ibid.
[491] The added weight could not yet be offset by engine output; aerodynamically it was unsound, and due to the thin construction of biplane wings fitting the very large and heavy Vickers type machine guns into a wing was highly impractical.

Sorley[492] has been credited (in fact he also credited himself) for the development of the 'eight-gun fighter', the first incarnations of which were the *Spitfire* and *Hurricane.* His assessment of the necessity for a fighter to have eight guns and be a monoplane was simply that, as mentioned above, a fighter must be able to catch a bomber:

> And it must have all the new features of retractable undercarriage, enclosed cockpit, flaps &c., in order to make it as fast as possible and so give the pilot his change of catching his enemy. Now, how to kill?[493]

The number of guns used in fighter aircraft had stagnated throughout the inter-war period. Originally, pilots armed themselves with pistols or rifles to combat enemy scouts and during the First World War there was a good deal of change in the armaments of fighter aircraft (indeed, armament changed as the concept of the 'fighter' evolved).[494] Variously, guns were mounted in front of the pilot, in the side of the fuselage or behind the pilot for use with a gunner in a two-man aircraft. Generally, there were one or two guns and they fired through the propeller which made the interrupter or synchronisation gear necessary. There was little change in these arrangements throughout the 1920s.

For Sorley, the problem facing fighter pilots as bomber technology improved fairly rapidly in the early-mid 1930s was holding the enemy bomber in their sights long enough to apply a measure of firepower sufficient to cause catastrophic damage. Sorley stated that "after much arithmetic and burning of midnight oil…reached the

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[492] Air Marshall Sir Ralph Sorley, was a Squadron Leader attached to the Operational Requirements section of the Air Ministry in 1933.
[493] Sorley, "Hurricane and Spitfire - Eight Guns for a Fighter."
[494] Robert F. Grattan, *The Origins of Air War* (London: I. B. Taurus, 2009). p. 87.

answer of eight guns being the number required to give a lethal dose in two seconds of fire".[495]

We have seen that designers within the industry and some at the Air Ministry lamented the fact that better machine guns were not a priority. By 1934 this was changing as the Browning .303 machine gun was starting to be tested in Britain. This was the gun to which Sorley pinned his hopes. However, as influential as he was in shaping the armament aspect of the *Hurricane* and *Spitfire,* the claims[496] that he was solely responsible for this development are "unfounded".[497] David Divine's assessment is probably the clearest example of this misconception:

> [The Air Staff] had also appointed Squadron Leader Sorley as early as 1930 to the Operational Requirements Department…to explore his theories of aerial gunnery. Against considerable internal indifference and some active opposition Sorley developed a theory that air fighting required the maximum concentration of hits within a period of two seconds.[498]

Like many parts of this story much myth has grown up around the issue of guns. The most common explanation for the eight-gun fighter is Sorley's moment of genius, just like the *Spitfire* is commonly held to have evolved directly from Supermarine's Schneider Trophy monoplanes. The myth is simple; a more accurate version is far more complex. Instead of simply 'burning the midnight oil' and doing some 'arithmetic', the idea for a fighter aircraft possessed of more than four guns was conceived much earlier. Sorley's theory that increasing bomber speeds would mean less time for fighter pilots to engage them actually originated in 1926. Recognising the potential implications of the increasing performance of enemy bomber aircraft, the AMSR at the time, Sir John Higgins, reckoned that faster bombers would mean less

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495 Sorley, "Hurricane and Spitfire - Eight Guns for a Fighter."
496 Price, *The Spitfire Story*. Mitchell, *Schooldays to Spitfire*. Sorley, "Hurricane and Spitfire - Eight Guns for a Fighter."
497 Sinnott, *The R.A.F. and Aircraft Design*: p. 114.
498 Divine, *The Broken Wing*: pp. 182-83.

time on target for fighter pilots and that they would therefore need a higher volume of fire.[499] For specification F.10/27 he specified six guns with four mounted in the wings. Colin Sinnott has stated that:

> The issue of fighter armament is one of perceived need *versus* feasibility. From 1926 onwards the need for greatly increased firepower was recognised. By 1934 it had become feasible to meet that need whilst retaining the essential performance characteristics of a fighter.[500]

Largely due to concerns over the added weight, much like the retractable landing gear, the idea to use six or eight guns was proposed long before it was actually feasible. The added weight had to be offset by increased power output, increased aerodynamic efficiency and lighter guns.

Proposals for increasing the number of guns for fighters was a fairly regular occurrence within the Air Staff. By 1930, four guns were specified for the *Bulldog* replacement and in 1931 trials were approved for the Gloster *Multi-Gun* fighter. The trials prompted the Aircraft and Armament Experimental Establishment (A & AEE) to state that one six-gun fighter was the equivalent of two conventional ones.[501] The A & AEE found in further trials initiated by Hugh Dowding, that a single seat multi-gun fighter was more likely than a two-gun single seat fighter to direct the amount of fire needed to a "vital part of a target aircraft".[502] By November 1932, Dowding wrote that he "cordially endorse[s] the contention…that complete destruction of enemy aircraft in one attack must be aimed at".[503]

Thus, the idea of increasing fighter firepower to counter the effect of increased bomber speeds did not originate with Ralph Sorely. Indeed, he did not join the Air

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499 Meekcoms and Morgan, *The British Aircraft Specifications File, 1920-1949*: p. 119. Sinnott, *The R.A.F. and Aircraft Design*: p. 112.
500 Sinnott, *The R.A.F. and Aircraft Design*: p. 112.
501 NA AIR 2/848 – A & AEE Report, Gloster F.10/27, July 1931, p. 20
502 Ibid., Long-Range Statistical Air Firing Trials to Examine the Fire Effect of a Multi-Gun Aircraft, 27th November, 1931
503 NA AIR 2/1323, Part IV, AMSR to SD2, 25th November 1932

Staff until January 1933.[504] He was, however, responsible for a key design change to the *Spitfire* and *Hurricane.* Originally designed with six guns in mind (three in each wing), Sorely proposed that the *Spitfire* and *Hurricane* could be adapted to meet the eight-gun standard that had been set in 1934. Writing in 1957, Sorely claimed that his "concept was right, but it was built up on rather a lot of imagination and would produce a totally different fighter from anything the fighter pilots were accustomed to. I was cautious, therefore, where I discusses these ideas in the early stages for fear of arousing reaction too soon…".[505]

The issue of guns stands as another example of the generally perpetuated myth of Air Staff stagnation in technical development. The issue of 'desire versus feasibility' is one that governed the adoption of different technologies, perhaps most notably the retractable undercarriage.

THE 1935 AIRCRAFT CONFERENCE

By 1936 a degree of design stabilisation had been achieved in military fighter aircraft. The *Hurricane* and *Spitfire* were the first monoplane fighters to enter service with the Royal Air Force in 1937 and 1938 respectively, and the *Spitfire* also made use of a metal skin. The fighter aircraft that followed them did so along broadly similar lines. Each was a monoplane and though not all of them made use of the metal skin their internal structure, the airframe itself, was metal. It is interesting to note that the complaints of historians about the 'quality' of RAF fighter aircraft cease after around 1935 and instead their focus turns to the 'production problems' of these aircraft. The

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[504] Sinnott, *The R.A.F. and Aircraft Design*: p. 113.
[505] Sorley, "Hurricane and Spitfire - Eight Guns for a Fighter."

reason for this, of course, is that the RAF fighters now ‘looked the part’ and outwardly were every bit as ‘modern’ as their Luftwaffe contemporaries.

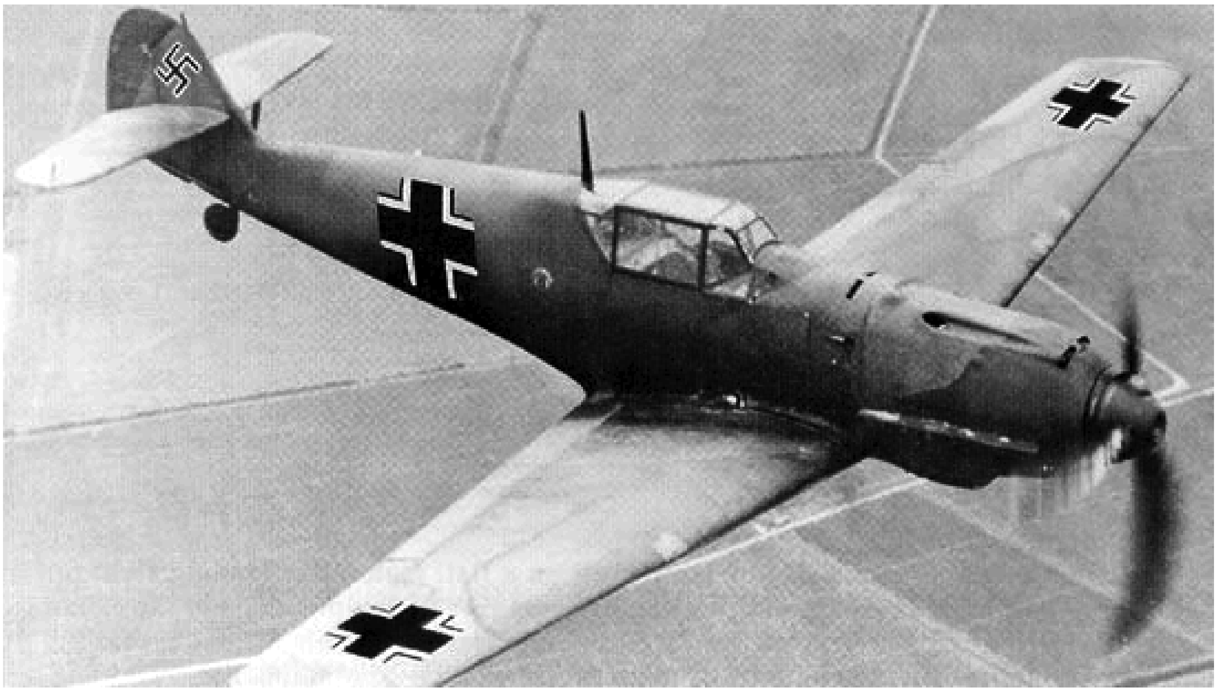

Figure 23 - Messerschmitt Bf 109 (1937)

Figure 24 - Hawker Hurricane (1937)

This point on the historiography is actually quite significant. It is difficult, if not impossible, to look at the development of inter-war military aircraft without viewing everything in terms of its potential value to the RAF at the outbreak of the Second World War and so most studies to some extent frame their arguments in these terms. The Air Ministry was, as we have seen, chastised for their apparent conservatism with regard to developing technologies (which we should now accept is not accurate). They are rebuked further by their delay and lack of interest in the De Havilland *Mosquito,* which we will look at later or for giving Frank Whittle the brush-off in the mid-1930s.

In looking at the shift from wood to metal and from biplane to monoplane we have seen that, broadly speaking, the community of practitioners engaged in aeronautical research and developing aircraft systems were resistant to change, and that for the most part the industry were driven to making such changes by the Air Ministry. This is not to say that the industry was not progressive, indeed it was, but the financial risk attached to making such changes without a guarantee of success dampened enthusiasm for untried and untested technologies. Yet we have seen the occasional private venture throughout the period, such as the Short *Silver Streak* or the Fairey *Fox*, which attempted to break away from what was seen as restrictive Air Ministry specifications and produce as good an aircraft as possible.

It seems that the research and development of aircraft and aircraft components between the wars followed three distinct lines. Firstly, state directed R&D in collaboration with the industry carried out at the National Physical Laboratory and the Royal Aircraft Establishment. An example of this was the adoption of metal for use in all RAF airframes, but in general the annual research programmes covered dozens of items.[506] Secondly, the research and development carried out at the firms themselves, often with support work carried out at the NPL and RAE. The Schneider Trophy provides the best example of this kind of development work where an aircraft was conceived at the firm and then wind tunnel work carried out at the NPL would develop the aircraft's aerodynamics. Also, in developing the *Spitfire* the RAE contributed a ducted radiator which helped reduce cooling drag and increase thrust.[507] Supermarine test pilot Jeffrey Quill related that:

> This [the ducted radiator] had been designed as a result of basic research work done at the Royal Aircraft Establishment by Dr. Meredith and had been a major factor in reducing the cooling drag which would otherwise have constituted a most serious 'barrier' to the performance of both the Spitfire and the Hurricane…Meredith's work at Farnborough was an excellent example of how basic research at the RAE could make a vital contribution to ad hoc design work carried out by industry.[508]

Finally there was the research carried out at Universities such as that conducted on fatigue and elasticity of materials for the ARC and Engineering Research Board, although at the time this kind of work was very limited.[509]

THE CONFERENCE

In 1935 the Aeronautical Research Committee (ARC) convened a conference to discuss the main aspects of aviation research.[510] The importance of this gathering of the great and good of British aeronautics should not be underestimated. Such a

[506] For instance, flaps, materials, engine components, aerodynamics, instruments, research on wing sections, propellers, stability and control and so on.
[507] Scott, *Vickers*: p. 203. Quill, *Spitfire - A Test Pilot's Story*: p. 94.
[508] Quill, *Spitfire - A Test Pilot's Story*: p. 94.
[509] NA DSIR 23/9679 – Work on Elasticity and Fatigue conducted at Universities for the Aeronautical Research Council and the Engineering Research Board (1922).
[510] The sessions were: 1. Aeronautical Research and the Industry; 2. Future Research on Air- and Liquid-Cooled Aero Engines; 3. Safety Problems on High Performance Aircraft & Future Research on Flying Boats and Seaplanes; 4. General Discussion.

gathering was a rare thing indeed. Various groups would meet at odd meetings of the Royal Aeronautical Society or industry or at government functions but this conference gathered the chief designers of the industry, research heads from the RAE and NPL, Air Staff, and some of the leading British scientists of the day, including Sir Richard Glazebrook, Sir Henry Tizard (who actually chaired the conference), and Professor Leonard Bairstow. There were further representatives of the Royal Air Force and some of the outstanding pilots and thinkers on aviation technology at the time, such as [Moore-Brabazon,] the ever-present Robert Brooke-Popham, and so on. Every area of aviation research and technology was represented save, perhaps, for the Universities, the work of which was in itself a topic of much debate. They gathered to discuss the present state of aeronautical research in Britain, where they were going wrong and what they could do to fix it.

Amongst the very first points raised on the first day was the role and functions of the Aeronautical Research Committee and the fundamental nature of the researches carried out by both the ARC and the wider industry. Professor Bairstow, who at that time was the head of aeronautical research carried out at the National Physical Laboratory, believed the industry was not inclined to help itself in regards to research and that the industry should be more collaborative amongst itself. Most significantly, however, he pointed out that research had moved from a concentration on stability and control of the aircraft to one of performance and that this could be problematic in the future:

> It seems to me that a time will come when the improvement of performance by better aerodynamic design will leave little to choose between the best products, and some new selling point will be wanted. I will hazard a guess that that point will be ease and harmony of control. Are not we losing sight of this problem in the intensive pursuit of performance, and can we guarantee that all other countries will be equally willing to limit themselves in that

> way? Responsible pilots in contact with responsible scientists seem to me to be required for an adequate attack on the problem of control, and much work can be done…[511]

As he saw it, the main problem for aeronautical research in the past, and indeed a problem that would continue into the future was the (often fractious) relationship between the industry and the ARC. The problem for the ARC "has been to get an opinion from the aircraft industry, at any rate in simple terms that members of the ARC can understand! Biennial meetings have been held for years between the SBAC [Society of British Aircraft Constructors] and the ARC, and in my opinion the SBAC has never presented a collective case".[512] This view was shared by Sir Henry Tizard who chaired the first session:

> …one such discussion which we had a short time ago. There were four members of the industry present, skilled people who were very much interested in an important detail – it was a detail, but a very important one – and three of them spoke at some length on what they felt to be the duty of the Aeronautical Research Committee to encourage and organise a certain line of practical development work. At the end of the meeting I said to the fourth member, speaking to him privately, "You did not take part in that discussion; why not?" and he replied "Oh, well, you see we have solved that already, and I do not agree with them at all"!
>
> Quite seriously, I ask you to consider my own position and the position of the other members of the Committee. The position is this, that the overloaded taxpayer is devoting more money to aeronautical research, in relation to size and –though I shall be unpopular in saying this – in relation to the importance of the industry, than to research in aid of any other industry. What is our position when we are asked to devote some more of the [p. 53] taxpayer's money to a problem suggested by two or three firms when another firm lets me know privately that they have solved it? I cannot recommend the provision of the taxpayer's

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[511] NA DSIR 36/4223 – Aircraft Conference 1935, Session 1 – Comments from Prof. L. Bairstow, p. 14.
[512] *Ibid.*

money to help one firm to do what another firm have done for themselves. I am not even in a position to know whether it is true.[513]

He advocated for the ARC to take what he termed 'the long view'.[514] That the ARC should not be bogged down in directing or undertaking short-term details or small individual pieces of research, on a particular type of high-altitude geared supercharger, for instance. Rather, the ARC should be directing and shaping the long-term path of aeronautical research, setting long-term goals to be achieved, letting the research establishments and industry decide which research pathways to take in order to meet them. We have already seen that this could, and did, work. The Air Ministry directed in 1925 that all RAF aircraft should be made of metal and that they would only consider machines made to this specification from 1930. The industry (somewhat grudgingly) obliged, and the setting of a long-term goal was met successfully by the industry.

Tizard also lamented the lack of:

> …the kind of thing which I was fortunate enough to get during the [First World] War, namely, close contact with users and manufacturers – close personal contact, not through committees. I do feel myself to be out of date and out of touch in some respects, and I should like to recover that touch as much as I can…anything which can be suggested to help people like myself to be in closer touch with the needs and views of designers, whose work, I assure you, we very greatly admire, will be of considerable value.[515]

Sir Henry concluded his point on industry-ARC relations by pointing out that:

> These are serious difficulties, and if we are to get this close touch, that I for one feel that I am in need of, it must be done through someone in the industry who really can represent their collective views on important technical matters. If he cannot, then it is obvious that the remaining things are things that are properly done by the industry itself. The proper things for

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513 *Ibid.,* pp. 52-53
514 *Ibid.,* p. 50
515 *Ibid.,* p. 51

the ARC to look after, apart from fundamental research, on which I think we are really all agreed, are those which practically the whole of the industry agree should be done, and which are best done by the National Physical Laboratory or at [The Royal Aircraft Establishment] Farnborough, rather than at any other institution.[516]

The conference aimed to improve the research process. More specifically, it looked to streamline the whole activity, from the identification of fruitful lines of inquiry, closer co-operation between the industry and the ARC, for the industry to undertake more research work, and for the industry itself to identify those areas where government conducted research would benefit the whole of the industry.

In his responses to questions during the final session of the conference, Major T. M. Barlow, Chief Engineer of the Fairey Aviation Company, touched on several very important and revealing points illustrating both the failings of the aeronautical research set-up in 1935 and highlighting areas where he, and many others, felt improvement could be made. The first and most important point was raised by Tizard in his opening remarks on the final day, in addition to those he made in the first session when he called for closer co-operation between industry, government and the research establishments. This was taken up by Barlow during his discussion. He began by reading the very last sentence of the United States Federal Commission Report on Aeronautics: “To draw the industry’s personnel engaged in the development of aeronautical products more directly in the planning of it’s research work”.[517] This was, in Barlow’s words, “…one of the things which we in the industry are pressing for”.[518]

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[516] *Ibid.,* p. 53
[517] *Ibid.,* Fourth Session, July 12th, ‘Authors Replies and Discussion, General Discussion, Chairman’s Closing Remarks’, Major Barlow’s Discussion, p. 4
[518] *Ibid.*

The structure of Barlow's remarks in the first instance covered various examples of "matters overlooked in this country and developed abroad" raised by members of the ARC or Air Ministry, most notably the Superintendent of the Royal Aeronautical Establishment at Farnborough and Group Captain Arthur Maund (at that point attached to the Air Ministry as Flying Operations officer). These included the retractable landing gear and the variable pitch propeller. For Major Barlow, as a prominent representative of the industry, he felt criticism directed towards the industry from government establishments such as the ARC and RAE, as well as the Air Ministry, were unfair: "Surely, this is an instance where the ARC's advice, if it ever gave any on these two points, was not sufficiently strong either to impress the industry or the higher officials of the Air Ministry? In fact, I was told personally about three years ago by a very senior official of the Air Ministry that they were not interested in the development of the variable pitch airscrew".[519]

As it happened (then) Air Marshall Sir Hugh Dowding, who was at that time the Air Member for Supply and Research took issue with Barlow's comment on this matter:

> I do not desire to join in any contentious discussion…[but a point] I want to make is in connection with something which Mr. Barlow said. He stated that a high official at the Air Ministry had told him that he was not at all interested in variable pitch airscrews. I do not know who that high official was, but, as the little boy said, "Please, Sir, it wasn't me". I have been the highest official at the Air Ministry concerned directly with technical matters for the last five years, and I can assure the Conference that not only my own policy but that of the Air Ministry as a whole has been wholeheartedly to encourage the development of variable pitch airscrews.[520]

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[519] *Ibid., p. 6*
[520] *Ibid.,* Air Marshall Dowding's Remark's, pp. 38-39

Dowding concluded by offering an explanation for Air Ministry policy on variable pitch airscrews:

> We have spent from first to last a good deal of money on the development of a British type, which, I am sorry to say, has been going very slowly; but if we cannot have a British type then we must have foreign types until the British type is ready – which I am sure it will be in due course. But I should not like it to get into the records of this meeting that the Air Ministry's policy has been in any way to discount or discourage the development of variable pitch airscrews, which is on the face of it of the greatest importance now and in the future.[521]

This exchange is revealing. Whether or not the Air Staff were concerned with variable pitch airscrew research, or indeed how highly they prioritised it is not as important or as interesting as the fact that a leading designer of the aircraft industry was under the impression that there was no governmental interest at all. This is precisely what Tizard and many others were calling for: a greater contact between industry and governmental research priorities. Clearer signals about where the industry should direct its own research, and more definitive goals attached to both long- and short-term research projects.[522] [similar case with retractable U/C]. The case of the retractable landing gear provides further evidence that research priorities were confused and that closer contact and collaboration between all parties concerned with aeronautical research could be highly beneficial.

In response to Group Captain Maund's suggestions that industry had perhaps been complacent in their search for a functional and efficient retractable undercarriage design, displaying a "lack of foresight", Barlow again placed blame more with the ARC than the industry: "…surely the ARC should be in a position to advise the Air

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[521] *Ibid.,* p. 39
[522] *Ibid.,* Major Barlow's Remarks, p. 8

Ministry or the industry on this problem? I venture to say that both knew the advantages [of retractable landing gears], but that we did not get the co-operation".[523]

Again, like Dowding, Maund, who was by no means technically conservative, gave evidence to the contrary:

> In 1930 and 1931 I asked a good many designers what they thought about retractable undercarriages; as a matter of fact, I asked six designers, and five of them told me that they had been into the question thoroughly and found that the extra weight was not worth the reduction of drag.[524]

Although Maund was actually responding to comments made by Frederick Handley Page on the 'conservatism of pilots', this confusion and lack of co-operation was getting in the way of important innovations that might have helped hasten along efficient monoplane designs for the RAF, or at least that was how it was seen by some within the industry and Air Ministry.[525] Why would Barlow spend his company's time and money developing, or helping to develop, variable pitch propellers and retractable undercarriages when he was under the very strong impression that the Air Ministry, and in a sense by extension, the governmental research establishments were, as far as he was concerned, categorically uninterested in developing them. As we have seen, Air Ministry specifications for fighter aircraft could be highly restrictive, as could the timetables for the design, development and production of a prototype for consideration under military trials (usually not more than twelve months after the issue of the specification).

It is startling to think that it took so long for the whole military-industrial complex surrounding aeronautical technology and research to wake up following the

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[523] *Ibid.,* Major Barlow's Remarks, p. 7
[524] Ibid., p. 45
[525] Most notably Henry Tizard.

Trenchard era. From 1930 until the Conference in 1935 aeronautical research had been considered to be lacking "research in structures, methods and technique".

> I am sure all will agree that we have overlooked this during the past few years and that we are trying to make up lost time rapidly now. It may be the industry's fault; it make be the fault of the ARC; but jointly we have to take the blame".[526]

Thus far, this part of the discussion has concentrated on the development of military aircraft generally. However, the conference also covered aero-engines, their research, design and development one the one hand, but more usefully to the conference-at-large was the discussion of research organisation as it related to engines. Major Barlow considered that the example set by engine research was adopted as the basis for Aeronautical Research Committee planning "…in conjunction with representatives of the industry on aircraft matters in general, we should go far to achieve the object of this conference".[527]

Arthur Maund pointed out that co-operation and close working arrangements which existed on the "engine side" were not present on the "aircraft side". Mr. Pye mentioned in his paper given to the conference on engine development that contracts were given for engine research problems to be carried out by the industry and in his remarks Major Barlow thought that there was "very little counterpart" on the aircraft side of things:

> On the military side the Ministry expect complete design, construction, tests, etc., of a normal size machine in one year. The specification possibly implies application of research and experiment of which the fringe has only been touched. That means to say that the design must be agreed within one month, otherwise there would be no hope of completion in the specified time. You will realise, then, the necessity of the industry not only being in the closest touch with research but having the information right up to date. They have to have the information

[526] *Ibid.,* Major Barlow's Remarks, p. 4
[527] *Ibid.,* Major Barlow's Remarks, p. 9

up to one month….what we do want is to be kept in touch, so that at the time we are aware of all the research of academic, fundamental or general application which is going on…In my opinion, as regards the engine side, there are more fundamentals which allow common discussion on different types. But can you imagine Mr Fedden, for instance, if after a year's intensive and expensive research he finds, shall we say, a new form of cylinder head or valve gear, immediately sending all the details to Major Halford or even to Mr. C. G. Grey![528]

This poses an interesting point. In an ideal situation the exchange and flow of ideas relating to military aircraft technology would be free. After all, it would have been in the best interests of the nation to have the very best aircraft possible, embodying the best of research and development carried out not just at the governmental research establishments but also from within the industry. Of course, this was not practical. While it was the practise of the Air Ministry to keep it's ring of manufactures "alive" during the inter-war period, the firms within the ring were interested in making the most money they could and the best way to do this was by developing or perfecting technologies that the Ministry would like but that no one else either had, or had perfected yet. The ARC was calling for greater contact between the research establishments and the industry, it also wanted more collaboration between firms of the industry developing aircraft but this was something that was incredibly difficult to achieve given that they were asking, in essence, for firms to give up any technical advantage they had, or might possess in the future.

Further, it is difficult to ask a company to spend time and money on what was often painstaking research, and then to simply make the results of that research available to any other firm. Indeed, the entire enterprise of research conducted within the industry was precisely to give them an advantage, when designing their new machines for

[528] *Ibid.,* Major Barlow's Remarks, pp. 8-10. Roy Fedden was the chief designer of aero-engines at Bristol. Major Frank Halford worked with Harry Ricardo designing and constructing aero engines. Charles Grey was editor of the *Jane's All the World's Aircraft* series and a prominent, at times controversial, aviation journalist.

tender, over the others. Nevertheless, this was precisely what the Chairman of the ARC was asking for; "a greater interchange of research information among the industry".[529] In his comments Barlow responded to this plea for greater interchange of research information by pointing out that:

> Now the majority of aircraft firms in this country have two markets – the British and the foreign, both highly competitive. At home the majority (military firms) have one buyer, the Air Ministry, who purchase by competitive selection in design and price. Abroad we are naturally not only in competition with British firms but with aircraft firms throughout the world. It is obvious that no firm will disclose any research or experiment which is being or likely to be of use in placing his aeronautical products ahead of his competitor. Such action would be business suicide, and I am sure, if the Chairman of the ARC was a shareholder in such a company and knew of such action which lost a contract, he would be the first to express his opinion in no mild terms.[530]

Barlow goes on to say that:

> The vital spark of progress in industry is competition. Cut that out and the aeronautical industry would become copyists with no initiative and no incentive for progress, and the country would lose. For those reasons, I do not hold that the industry should agree to the interchange of their own research. Research which can be freely discussed are fundamentals and points of general application, but why bring in another body, such as the proposed Industrial Research Association, for this? I see no place for the ARC if there were such an Association. The ARC would be less than advisory – more of a Post Office, passing on information to research institutions…All members of this Conference will agree that co-operation in necessary, but what we do not apparently agree at the moment is the form it should take.[531]

Roy Fedden, mentioned in his response to remarks made about his paper on engines that

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[529] *Ibid.,* p. 10
[530] *Ibid.,* p. 11
[531] *Ibid.,* p. 11

…of late both our Military and Civil aircraft have, generally, fallen to a seriously low level of performance, which matter must be remedied as soon as possible, and must be prevented from occurring again in the future. With all due deference, I submit that a real diagnosis of the trouble has not been given. I believe we have the necessary research organisation and research workers, but that they are not adequately directed and organised, and that we can never hope to regain and remain in the forefront of aircraft development, so vital to the safety and welfare of this country, until we appreciate these two essential points.[532]

Fedden called for a small, elite, carefully chosen and permanent staff to prioritise and direct research work; in his words a "thinking department". In theory, of course, this was done at the ARC and Air Ministry. However, in practice the frequent changes of personnel within these institutions made it difficult to get any sort of real consistency in what was sought with regard to aeronautical technology. Fedden's suggestion called for a smaller, permanent group would "formulate policy, see the complete picture, and then direct and instruct, what I believe are already adequate research organisations, what to do, and the priority of the work".[533]

It was also suggested that:

…secrecy was holding back wider information in certain respects. I think the industry as a whole need not shoulder the whole of that blame, because there is the Air Ministry's secrecy regarding service aircraft which is considered by quite a number of people to be really, if I may be so bold as to say it, ridiculous, since the information is generally available to all the foreign Legations.[534]

In the general discussions that followed, there were constant lamentations of the lack of practical focus in British aeronautical research. However, the Conference itself seemed to have abated those concerns somewhat, but still criticism of the nature of the technical publications by the NPL, for instance, was common and, it seems, a

[532] *Ibid.,* Roy Fedden's Remarks, pp. 17-18
[533] *Ibid.,* p. 18
[534] *Ibid.,* Mr. Radcliffe's Remarks, p. 20

serious stumbling block to the practical application of research knowledge as related by Stanley Evans of Heston Aircraft Co.:

> …I believe that there is still some hope for a more practical orientation in our research programme…This recurrent plea for so-called "long distance"[535] research has been the wail of our professors and scientists for many a year; moreover, in this country, I strongly suspect that they worship the abstract science of the German worker, while silently scoffing at the industrial research outlook of the Americans. They ask to be left alone in their "cloistered studies", while the engineer must sell the product of his art on the industrial battle-front or perish. All the same, I am quite willing to forgive those transcendental publications of the [Aeronautical Research Committee], after wandering through the delightful gardens of the [National Physical Laboratory] on Wednesday afternoon. I, too, might be in favour of "A Modification of Oseen's Approximate Equation for the Motion in Two Dimensions of a Viscous Incompressible Fluid" if <u>MY</u> Drawing Office window looked out across the City of Dreaming Spires!

In essence the Conference revealed two distinct but interrelated problems concerning British aeronautical research. In the first instance, the research directed and carried our by the NPL and ARC seems to have been overly complex. As Stanley Evans put it "The scientist may be interested purely in the explanation of phenomena, but the engineer has to produce a better machine". Despite the tongue-in-cheek reference to the work of the NPL made by Evans, he was raising a serious point. How is he to apply such research to the design of one of his aircraft? The other problem facing research was, what might be called, competition or collaboration. For some of those present at the conference competition within the industry was vital to the development of successful aircraft, for others, greater co-operation between designers and firms of the industry was crucial.

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[535] That which is far removed from any significant practical application.

The simplification of technical and research reports from the Aeronautical Research Committee was perhaps the most significant outcome of the conference. Simpler reports, and perhaps a tighter research focus allowed for a greater dissemination of centrally conducted work directed and carried out by the ARC, NPL and RAE. However, its emphasis on improving the way research and development work was conducted was a big step forward from what had been going on since the First World War.

'I Don't Give a Bugger Whether it's Elliptical or Not, so Long as it Covers the Guns': Supermarine, Hawker and the Search for a 'Real Killer Fighter'

It is not necessary here to relate the full histories of the *Spitfire* and *Hurricane* - they have been done many times before - but this section will draw attention to some of the design origins and changes experienced by both of these aircraft. The Air Staff had been pushing for significantly improved fighters for some years before the *Spitfire* and *Hurricane.*[536] A monoplane was specified as early as 1931, the idea of the multi-gun fighter was posited as early as 1926, and the idea that fighter aircraft must have much improved performance so as to compete with the increasing speeds of enemy bombers was realised around the same time.

It is again worth pointing out here that conventional wisdom surrounding the Air Ministry and aircraft industry of this period shows an industry woefully inadequate to the task before them, clinging desperately to the 'bread and butter' biplanes that served them so well throughout the 1920s. The Air Ministry is often simply seen as

[536] They wanted monoplanes, with multiple guns capable of downing a bomber in around two seconds of fire, with significantly improved performance in terms of speed and rate-of-climb.

backwards, moronic, badly managed and frustratingly slow to act. Therefore, the emergence of the *Spitfire* and *Hurricane* is portrayed as something of a minor miracle. No real attempt is made to understand where they came from and how they were developed, how their design changed or the fact that these two aircraft were the ones that Air Member for Supply and Research (AMSR) Hugh Dowding was pursuing almost as soon as he came into his new position as the head of aircraft development and procurement in 1930. In fact, so convinced was he of the need to secure the very best fighter aircraft possible, he ordered both the *Spitfire* and *Hurricane* without consulting the Air Staff.[537] In 1933 a memorandum discussing the development of interceptor fighters mentioned that:

> It seems certain that political considerations will always force us (at any rate in war) to maintain in our defence a certain number of Fighter aircraft giving the highest possible margin of superiority over contemporary Bomber aircraft.[538]

For the sake of clarity, given the often confusing amount of specification numbers, aircraft names and lines of development, it will be helpful before going further to state as clearly as possible what we will be talking about in the following section:

- The emergence of the *Hurricane* and *Spitfire* came from two different searches for two different types of fighter. The Hawker *Fury* was the RAF interceptor fighter then in service and the Bristol *Bulldog* was the zone fighter.
- F.7/30 was the original search for the Bristol *Bulldog* replacement. The relevant aircraft designed to this specification were the Supermarine *Type 224* monoplane and the Gloster *Gladiator* biplane (which was eventually accepted). F.7/30 was issued 1st October 1931.

[537] Sinnott, *The R.A.F. and Aircraft Design*: p. 32.
[538] NA AIR 2/2741 – Interceptor Fighter: Specification F.5/34, Pros and Cons for the retention of Specialist Day Fighter, June/July 1933

- F.37/34 was for the modified Supermarine *Type 224* (the *Type 300).* It was issued in January 1935 thought the decision to order the aircraft was taken in September 1934.
- F.5/34 was the original search for the Hawker *Fury* interceptor fighter replacement. This specification was issued in November 1934.
- F.36/34[539] although no specification was issued this number covered the Hawker high speed monoplane design proposal. The decision to order this aircraft was also made in September 1934.
- F.10/35 is perhaps the most significant. It was agreed in March and issued in April 1935. It was decided that the Hawker and Supermarine designs (F.36/34 and F.37/34 respectively) could be developed to meet this specification – these eventually became the *Hurricane* and *Spitfire.*

Figure 25 - Hawker Fury

539 NA AVIA 8/166 – Development of Hawker Fighter Monoplane F.36/34

Figure 26 - Bristol Bulldog

The first proposals for what would eventually become the Hawker *Hurricane* came directly from conversations between the Directorate for Technical Development and Sydney Camm, the Chief Engineer at Hawker Aviation in 1934.[540] The proposal was for "a method of overcoming the limitation of the existing high speed *Fury* due to its biplane construction".[541] For the Deputy Director of Technical Development (DDTD) problems with the Hawker *Fury* had arisen largely due to the fact that Hawkers would not separate high speed development from military utility and felt that their new

[540] NA AIR 2/605 –'Proposal for High Speed Monoplane by Hawker Aircraft Limited' - Hawkers High Speed Private Venture F.7/30, DDTD to DTD, 19th February, 1934
[541] Ibid.

proposal would be no different.[542] The original Hawker proposal in January 1934 specified a top speed of 255 mph at 15,000 ft with a fixed undercarriage.[543] DDTD considered that "ultra high speed development must be associated with a monoplane" and that "the Supermarine F.7/30 [the *Type 224*] if successful may offer an opportunity to proceed with that work".[544]

The Hawker proposal was thus delayed between February and September 1934 while performance figures were presented for the Supermarine *Type 224*. Eventually, it became clear that the performance of the *Type 224* was poor and the engine was particularly unsuitable. Hawkers continued the design work in spite of having no assurances from the Air Ministry and redesigned their aircraft to take advantage of the Rolls-Royce *P.V.12* engine, first run in 1933 (which would later become the *Merlin*) replacing the troublesome *Goshawk*.[545] They considered that a speed "approaching 300 mph appears possible".[546] By September 1934, in light of the disappointing performance of the Supermarine F.7/30 design and the promise of a better, more flexible machine from Hawkers, DDTD recommended the "ordering of this aeroplane as part of this [high speed] work apart from the question of the *Fury* replacement".[547] His intention was to continue the search for an adequate replacement for the *Fury* (through Specification F.7/30, for instance) and continue with the Hawker proposal for a high speed monoplane.

In the revised September 1934 proposal the Hawker design embodied many of the features that would be seen throughout the Second World War: it was a cantilever

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[542] DDTD meant that Hawkers would not pursue a purely high-speed aircraft if it meant sacrificing military utility.
[543] NA AIR 2/605 - DTD to AMSR, 22nd February, 1934
[544] Ibid.
[545] Ibid., Sydney Camm to DDTD, 4th September, 1934
[546] Ibid. Hawkers quoted 298 mph at 15,000ft
[547] Ibid., DDTD to DTD, 10th September, 1934

monoplane and “every effort [had] been made to reduce the drag to the practicable minimum and to this end, the undercarriage, tail wheel and radiator are fully retractable and the pilot completely enclosed”.[548] The proposal from Hawkers also highlighted the fact that it could be used as both an interceptor *and* as a zone fighter. In addition, the revised proposal contained provisions for a high lift device to keep the landing speed within the specification.

The retractable undercarriage that was first investigated at Hawkers during December 1933 was a key aspect of the design. The fixed cantilever undercarriage used by the Supermarine *Type 224* and specified in the original Hawker proposal for a high-speed monoplane was largely incompatible with the desire for a truly high-speed aircraft as the parasitic drag of a fixed undercarriage could contribute up to around 40% of the total drag of a complete airframe.[549] The elimination of such a component, even with the attendant weight attached to a retractable mechanism would prove significant. Yet the power of aero-engines was, before the Rolls-Royce *P.V.12* at least, not enough in some cases to justify the increased weight of a retractable undercarriage mechanism.[550]

While Sydney Camm was getting approval from the Air Ministry for his high-speed low-wing monoplane fighter, Supermarine were in the midst of tendering for Specification F. 7/30. For the firm, F.7/30 was a minor disaster. Having spent years designing aircraft which were amongst the fastest in the world the Air Ministry requirement of 250 miles-per-hour seemed “a piece of cake”.[551] Supermarine’s effort was the *Type 224* and was, in the words of one prominent Supermarine historian

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[548] Ibid., ‘Proposed Hawker Interceptor Monoplane’, 1st September, 1934
[549] S. Scott-Hall, "Wheel Brakes and Undercarriages," *Flight* XXIII, no. 50 (1931): p. 1225.
[550] Anon., "British Aircraft," *Flight* XXIV, no. 47 (1932): p. 1072.
[551] Scott, J. D., *Vickers – A History*, (London, 1963), p. 179

"decidedly unlovely".[552] It fell short of the Air Ministry requirement by 20 miles-per-hour and the engine, the Rolls-Royce *Goshawk*, constantly overheated.[553]

Sir Robert McLean, the Chairman of Vickers-Armstrong and Supermarine, felt that "they [his design team] would do much better by devoting their qualities not to the official experimental fighter, but to a real killer fighter…".[554] Thus began the 'private venture', outside of Air Ministry funding and control, between Supermarine and Rolls-Royce that was to become the iconic *Spitfire*. It was not a strictly private venture however, despite McLean's best intentions. The Royal Aircraft Establishment (RAE) at Martlesham Heath contributed a ducted radiator for the pressure water-cooled *Merlin* engine, calculating that it would give some thrust, significantly reducing the cooling drag.[555] Initial reports prompted the Air Ministry to issue a new specification for the Supermarine design (F. 37/34) with specifications that made the aircraft qualify for adoption.

It is often stated that the *Spitfire* was a direct descendant of the *S* series monoplane racers R. J. Mitchell designed for the Schneider Trophy. In actuality there was little about the *Spitfire* that resembled the earlier *S* series aircraft. The aircraft designed for the Schneider Trophy did, however, convince Mitchell that the monoplane was the superior form in terms of performance, and that for fighter aircraft, where performance was absolutely paramount, the monoplane must be used. This is evidenced by his *Type 224* which, although a failure, did not dissuade him from designing monoplanes.

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552 Price, Alfred, 'Spitfire Prototype and Mark I', *Aeroplane*, (March, 2006), p. 8
553 Ibid. p. 2
554 Scott, *Vickers*, p. 202
555 Ibid. p. 203. This ducted radiator was also applied to the Hurricane, giving the same benefit.

The Schneider Trophy was also significant in the eventual development of the *Spitfire* as it began an important relationship between Supermarine and Rolls-Royce who would eventually supply the *Merlin* engine for use in both the *Spitfire* and the *Hurricane.*

The poor performance of the *Type 224* in the F.7/30 trials prompted an immediate response from Supermarine. Even as the *Type 224* was undergoing preliminary trials at the Royal Aircraft Establishment at Martlesham Heath, Supermarine were discussing an improved design with the Air Ministry.[556] Although heavily based on the *Type 224* design Mitchell systematically removed or changed all the things he believed were impeding performance. The new design, the *Type 300*, was to have a retractable undercarriage, it was to lose its corrugated wing leading edge and reduced the span by six feet. All these things would improve the performance and a general clean up of the design added to this. Chief Draughtsman at Supermarine, Joe Smith, reported that Mitchell was:

> …an inveterate drawer on drawings, particularly general arrangements. He would modify the lines of an aircraft with the softest pencil he could find, and then re-modify over the top with progressively thicker lines, until one would finally be faced with a new outline of lines about three-sixtheenths of an inch thick. But the results were always worth while, and the centre of the line was usually accepted when the thing was redrawn.[557]

The estimated increase in speed resulting from these changes was around 30 mph to give a top speed of roughly 265 mph using the *Goshawk* engine. The *Type 300* was also to be included in the High Speed development programme and that it should be ordered as

> …a suitable type on which to overcome many of the problems we shall have later with the 8 gun interceptor e.g. the combination of steam cooling, retractable undercarriage and guns in

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[556] Price, *The Spitfire Story*: p. 14.
[557] Ibid., p. 16.

> the wings. It will also be a most interesting experiment with wing flaps on a high performance monoplane.[558]

The decision to order the modified Supermarine F.7/30 (the newly designated *Type* 300) design along with the Hawker high-speed monoplane shows that the Department of the AMSR "demonstrated an awareness of need and speed of decision making for which the department is seldom given credit".[559]

As mentioned above, the Hawker high-speed experimental monoplane was being developed at the same time as the Supermarine F.7/30 design, though along different lines and from different origins. During the Spring of 1934 the Hawker *Fury* replacement was resurrected after some delay. Revised performance estimates were undertaken to account for more modern engines, the Fairey *Prince* and Rolls-Royce *PV. 12*, both liquid cooled in-line 785 hp engines. Squadron Leader Sorely, *de facto* head of the Operational Requirement (OR) section recommended that top speed should be prioritised over Rate of Climb (ROC).[560] This change in priorities represented a major shift in one of the main requirements for home defence single seat fighter aircraft as ROC had always been the preferred optimisation. Defining the operational requirements for the *Fury* replacement became more urgent following reports from overseas as the Director of Technical Development [DTD] related to the OR section:

> We receive from [Air Intelligence] reports of high speeds claimed for fighters built abroad. As our new Fighter Specifications F.7/30, F.5/33, and F.22/33 all sacrifice performance for other operational requirements, the situation may arise shortly that our fastest fighter is very much slower than some foreign fighters.[561]

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[558] NA AIR 2/2850 – Single Seater Day and Night Fighter to Spec No. F.7/30, DTD to AMSR, 23rd August 1934
[559] Sinnott, *The R.A.F. and Aircraft Design*: p. 96.
[560] *Ibid.,* OR to DCAS, 5th July 1934
[561] *Ibid.,* DTD to OR, 17th July 1934

Specification F.5/34 was issued in November 1934 and was intended to produce a new interception day fighter. It called for a maximum speed of not less than 275 mph at 15,000 ft and it was to be armed with eight machine guns[562] and prototypes were ordered from Bristol and Gloster in 1935.[563] Some time later, however, the restriction to day flying only, as required by interception fighters, was dropped and specification F.5/34 (and the Bristol and Gloster machines) were brought into line with the F.10/35 Zone fighter specification.

The F.10/35 specification for a new zone fighter continued the *Fury* replacement's priorities of speed and firepower over ROC and manoeuvrability. Whereas the issue of landing speed had held up F.7/30 for some time, it was not discussed at all in F. 10/35. The use of flaps to control landing speed without sacrificing the top speed too much was widespread by 1935.[564]

> Specification F.10/35 was written with the Hawkers high-speed monoplane proposal and the Supermarine *Type 300* in mind. In general terms the Air Staff required:
>
> …a single-engine, single-seater day and night fighter which can fulfil the following conditions:-
>
> a. Have a speed in excess of the contemporary bomber of at least 40 mph at 15,000 ft.
>
> b. Have a number of forward firing machine guns that can produce the maximum hitting power possible in the short space of time available for one attack. To attain this object it is proposed to mount as many guns as possible and it is considered the eight guns should be provided.

By this time, Air Ministry had moved from issuing highly specific, and, according to the Society of British Aircraft Constructors, highly restrictive specifications to ones that were more general, emphasising, as in the case of F.10/35 "the maximum

562 *Ibid.,* Spec No F.5/34. Single Seat Fighter, 16th November 1934
563 NA AIR 6/22, ACM 572, Progress on Experimental Aircraft, 30th April 1935
564 Sinnott, *The R.A.F. and Aircraft Design*: p. 93.

possible". In terms of speed the aircraft should be capable of "not less than 310 mph at 15,000 ft" and the rate-of-climb should be "the best possible to 20,000 ft, but secondary to speed and hitting power". In terms of armaments the Air Staff specified that not less than six guns "but eight are desirable" and the guns themselves were to be located outside the airscrew.[565] To give some idea of just how far specifications had come, in 1931 when F.7/30 was issued it was several pages long and contained fourteen very detailed items for designers to consider. F.10/35 was two pages long and contained seven short items the most specific of which concerned performance. Hawker and Supermarine had to a great extent demonstrated to the Air Staff what designers could do if allowed a freer hand in the conception of their aircraft.

The development of the *Spitfire* yields some important information about relations between the firm and the Air Ministry. The first level-speed runs for the *Spitfire* were disappointing, showing a top-speed of some 335 miles-per-hour, which was little more than the Hawker *Hurricane* (being developed at the same time).[566] The Ministry had much higher hopes for the *Spitfire*: in 1936 the Air Member for Research and Development (AMRD) noted that "…[there is] no doubt that the Supermarine design holds out the best promise of providing the best aeroplane for the use of the service"[567]. However, because the *Spitfire* was more time consuming to make, it needed to have a significant advantage in speed over the *Hurricane*, or production would not be justified.[568] Due to the disappointing initial speed, there was little point in sending the prototype to the RAE for official trials until a greater performance could be achieved. The fixed-pitch wooden propeller came under

565 Price, *The Spitfire Story*: p. 35.
566 Quill, J. K., *Spitfire – A Test Pilot's Story*, (Crecy, 2005), pp. 84-85
567 NA AVIA 10/90 – Survey of Airframe Production - Memo from AMRD, 19th November 1936
568 Overy, Richard, *The Air War, 1939-1945,* (New York, 1980), p. 21. By 1939 it took 2 ½ times the man-hours to produce a Spitfire as it did a Hurricane.

suspicion and was changed, affording an extra 13 miles-per-hour, giving a maximum speed of 348.[569]

Jeffrey Quill, a Supermarine test pilot, recounted that:

> K5054 [the Spitfire prototype] was flush-riveted throughout in order to achieve the smoothest possible surface finish, which the aerodynamicists regarded as vital for drag reduction at high-speed. But since flush riveting was difficult, expensive and time-consuming in production, a practical trial was decided upon. Several bags of dried split peas were purchased…To each of the many thousands of flush-headed rivets all over the outer surface of the aircraft, a split-pea was attached…thereby virtually converting each into a round-headed rivet. I then took the aircraft up and carried out a very careful series of level-speed runs…the effect on the aircraft's performance was certainly significant – something in the order of 22 m.p.h [was lost].[570]

While clearly unconventional, this relatively inexpensive set of tests (carried out by the firm) afforded them the opportunity to identify where the more expensive and time-consuming flush riveting could be avoided.

REARMAMENT: 1934-1939

This section will examine the rearmament schemes between 1934 and 1939. The plans themselves had limited effect on the shaping of aircraft technology but they are important in understanding RAF and Air Ministry policy during the years leading to the Second World War. Parity with the German Luftwaffe was paramount, as was bringing through the most advanced first-line fighter aircraft that could be developed. They also show the Air Ministry's increasing commitment to the 'modern' monoplane fighter.

In 1931 the Aircraft Supply Committee reported that on average it took between 5 ½ and 6 ½ years from conception to the first delivery of aircraft to the RAF (up to 8

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569 Quill, *Spitfire*, p. 95
570 Ibid. p. 108

years for a large aircraft such as a bomber).[571] Hand in hand with the rearmament programmes that would come, the Air Ministry was anxious to accelerate the design and development of aircraft. A report on new types of service aircraft noted that:

> The subject of delays and delivery of experimental aircraft has been under discussion with the SBAC for some time, but last year the necessity of expansion gave it a new and altogether greater prominence.[572]

And also that:

> It is impossible to pursue any rational plan of re-arming unless new types can be developed so as to be ready when they are required: and to ensure acceptance of such a programme by the firms it is necessary that it should be vigorously and impartially enforced…it has always been possible for the constructor to escape criticism for his failure to comply with delivery promises, on the plea (justified or not) of interruptions in production through meeting [Directorate of Technical Development] requirements. There is widespread demand in the industry for a freer hand and it is considered that if this demand is accepted it should lead not only to quicker deliveries but to more enterprising and original design.[573]

The beginnings of rearmament in 1934 were stimulated by several factors, not least of which was the changing political situation in Europe. However, the expansion of the military aircraft industry was based upon the government's realisation that their small "ring" of manufacturers would not be sufficient in times of war.[574] This subject was tackled in 1927, and as a result the 'shadow factories' scheme of 1936 was based upon this comprehension.[575] So how did the military aircraft industry expand and cope with the changing demand of the government?

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[571] NA AIR 6/22 – 'New Types of Service Aircraft – Acceleration of Design and Development', Undated, likely 1935 due to the reference of expansion programmes beginning the previous year., p. 1
[572] Ibid.
[573] Ibid., p. 2
[574] Fearon, Peter. 'The British Airframe Industry and the State, 1918-1935', *The Economic History Review, New Series*, Vol. 27, No. 2, (May, 1974) p. 8
[575] *Ibid.,* p. 8

The 'ring system', conceived in 1919 succeeded in its objective of keeping a hub of aircraft and engine manufacturers operational during the 1920s when the market for new aircraft was very low. While the system did keep the industry alive during this period it was limited, primarily by the funding available to the Air Ministry for the procurement of new aircraft at this time.[576] Furthermore, it had the undesirable effect of producing too many different types of aircraft, and short production runs made the aircraft that were produced more expensive. The most pressing problem however, was that no single firm could adequately gauge production runs because orders were given on a yearly basis. With this in mind we must now turn to the beginnings of expansion of the industry and its relative place within the world market for military aircraft.

Having taken into consideration these problems of the aircraft industry in 1925[577] the government set about the planning of the expansion of the industry with a series of 'Schemes'. The first major and focused example of these, 'Scheme C', did not appear until 1935, but it was the first plan for the general expansion of the military aircraft industry and subsequently the RAF.[578] The plan was set to begin in May 1935 and give the Metropolitan Air Force (MAF)[579] a first-line strength of 1,512 aircraft. Under this scheme some 3,800 aircraft would need to be produced by 1937. It was still limited, in that aircraft of the modern design, that is, all metal constructed monoplanes, were still being ordered in small quantities.[580] This was revised in the next plan 'Scheme F', which made the procurement of modern monoplanes a high

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[576] However, government expenditure on the Air Force increased from 1923-1933; see Postan, *British War Production*, Table 1, p. 2

[577] Fearon, Peter. 'The British Airframe Industry and the State, 1918-1935', *The Economic History Review, New Series*, Vol. 27, No. 2, (May, 1974) p. 9

[578] Ritchie, *Industry and Air Power*, p. 3

[579] The MAF was for the defence of Great Britain and London.

[580] *Ibid*., pp. 41-2, Note: Examples of these small production orders for the modern design are given as 150 for the Fairey 'Battle' and 96 for the Vickers 'Wellesley'.

priority, ordering 600 Hurricanes in February 1936.[581] An interesting point is raised here. Though the first Hurricanes were ordered in February 1936, the first Spitfires were ordered four months later in June. 300 Spitfires were ordered, to be produced by March 1939[582]. Declinist historians often turn to the fact that the first Spitfires were not delivered until seven months after the first Hurricanes as an indication of the inefficiency of Supermarine[583], but as we will see later on there were several factors that influenced these delivery times. Such as the continuous upgrading of the Spitfire and the Rolls-Royce Merlin aero-engine, and we must also look at the Air Ministry's considerations over which was the better aircraft.

In any event, it was not the function of the 'Scheme' system to provide Britain with anything close to war production - that would come later in the War Potential Programme.[584] However, it is possible to chart the progress of the 'Scheme' system with the changing political situation in Europe. 'Scheme L' was accepted after the *Anschluss* and was to increase the MAF first-line strength by 37 per-cent, and within this figure, fighter production was to be raised by 45 per-cent[585], this would require the production of 12,000 aircraft over two years. Again, following the Munich crisis the decision was taken to further increase the first-line fighter strength by twelve squadrons, or 192 aircraft.[586] We must now turn to specifics, and look at the debates surrounding the expansion of production.

Barnett's major argument pertaining to aircraft production is that production quotas were never fully met and that we can use this as a measure of its effectiveness.

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581 *Ibid.,* p. 42
582 NA AVIA 46/119 Mr Grinstead's Papers
583 Barnett, *Audit*, p. 139
584 Ritchie, *Industry and Air Power,* p. 3, this would aim to give Britain the capacity for producing 2000 aircraft per month by the end of 1941.
585 *Ibid.,* p. 43
586 *Ibid.,* p. 43

This is a view shared by Postan in his *British War Production*, but it is misleading. While it is true that production quotas for aircraft were not, for the most part, fully met, we must again apply our considerations of relativity. From 1934 Germany's expansion programmes were revised almost every time Britain's were (out of chance and necessity rather than by design). The first German *Lieferprogramme,* called for only 294 aircraft, however, a substantial revision was made with the second *Lieferprogramme* aiming to produce 17,015 aircraft in the 1934-1938 period, the majority of which was to be trainer aircraft.[587] However, targets could not always be met and eight subsequent revisions were made to German plans between November 1936 and March 1939, ending with Plan 11, and a forecasted production of 24, 317 aircraft over thirty-seven months.[588] The two major problems that necessitated this fairly constant updating of aircraft production plans were, firstly, the number of new types to be introduced constantly changed, and secondly, modifications to existing types held up production.[589] These are the same problems that Britain, and in fact every other nation, faced. In France, from 1932 until 1934 they produced no aircraft at all; the situation there was old equipment and small orders, which could not be fulfilled by the available industrial and administrative resources.[590]

	1932	1933	1934	1935
France	-	-	-	785
Germany	36	368	1,986	3,183
USA	593	466	437	459
Great Britain	**445**	**633**	**740**	**1,140**

Aircraft Production of the Major Powers 1932-35[591]

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587 Richard Overy, "The German Pre-War Aircraft Production Plans: November 1936-April 1939," *The English Historical Review* 90, no. 375 (1975): pp. 1-3.
588 *Ibid.,* p. 3
589 *Ibid.,* p. 2
590 Richard Overy, *The Air War* (New York1980). p. 21.
591 *Ibid.,* p. 21

Table 1 illustrates the international situation from 1932-35, and by 1935 air parity with Germany had become a serious problem, this was achieved and then exceeded but not until later on. We cannot judge the health of the industry by looking at its output alone, though a steady rise in the production of aircraft can be seen in the table above, and this continued until the end of the Second World War.

In Britain, the first general expansion scheme, Scheme 'A', was introduced in 1934 and aimed to produce 1,252 first-line aircraft.[592] Being far too limited this was consequently scrapped in favour of the much more concentrated Scheme 'C'. This scheme aimed to produce 4,126 aircraft and 4,372 engines over the next two years.[593]

Furthermore, in 1934, the government promised air parity with Germany, who was by then rearming. However, it was also the product of a series of reports commissioned by the Air Ministry to investigate British aircraft production. Commencing in 1931, the Aircraft Supply Committee (ASC) provided the Air Ministry with an annual overview of aircraft production. After World War One, Britain had a surplus of 22,600 airframes and 38,500 aero-engines.[594] In part, it was because of this massive surplus that it took so long for the Air Ministry to address the problems of obsolete types of aircraft and also the introduction of modern types.

Year	**Air Ministry Expenditure**	**Payments to Supermarine**
1923	£3,602,000	£129,000
1924	£5,341,000	£97,000
1925	£5,598,000	£167,000

[592] Ritchie, *Industry and Air Power,* p. 41 Note: This scheme was not due for completion until 1939.
[593] NA T161/836 – Treasury Memo, RAF Expansion (1935)
[594] NA AIR 2/1322 – ASC Report (1931), Appendix IV, p. 35

1926	£5,008,000	£308,000
1927	£5,080,000	£308,000
1928	£5,094,000	£250,000
1929	£5,837,000	£332,000
1930	£6,487,000	£248,000

Air Ministry Expenditure 1923-30[595]

So, by 1935, expenditure on the RAF had risen considerably, indeed, enough for the first general expansion programmes to be brought in. Scheme 'C' is the first clear illustration that the Air Ministry had moved from its counter-productive sensibilities of small production runs and the constant introduction of new types of aircraft, to a more concentrated programme of fewer types and longer production runs, essentially enabling more aircraft to be built. However, the major benefit from Scheme 'C' was the incorporation of the all-new, all-metal monoplane.[596] The Air Ministry had been suspicious of the change to this radical new technology for several reasons; in the first instance, it was a matter of cost. The change to the metal monoplane required the large-scale investment in new jigs and tools for metal construction costing nearly £200,000 for each facility.[597] While this is a reasonable concern, there was a further worry that the small orders being farmed out by the Air Ministry would not be sufficient to make this change worthwhile.

THE EXPANSION OF THE RAF: 1935-39

So, as has been seen, it was in 1935 that the first general expansion orders for the RAF commenced. The Treasury estimated the cost of the 4,126 airframes and the 4,372 engines under Scheme 'C' at £12,500,000 spread over two years. The Air

595 NA AIR 2/1322 – ASC Report (1931)
596 Ritchie, *Industry and Air Power,* p. 3
597 NA AIR 20/3575 – Director of Aircraft Production (D.A.P) Report on Airframe Supply, 10th January 1938 p. 6

Ministry, however, gave an estimate rather higher than that, some £16,500,000. This led Mr E.E. Bridges of the Treasury to write to Mr A.H. Self of the Air Ministry that "…we are growing accustomed to shocks in these days; but your statement that the provisional total of £12,500,000 for the expansion scheme…has risen to £16,500,000, ranks as amongst the largest and least pleasant shocks hitherto administered to us".[598] Self replied that "…it should come out at about £16,000,000 against the £16,500,000 mentioned in my letter…".[599] With the Air Ministry justiying this additional spending by the "ordering of additional aircraft of new types…to eliminate certain of the older and smaller types" and also that "it is the result of purchasing…larger airframes, taking two engines…".[600] This exchange between departments of the government serves two purposes. Firstly, it illustrates the obvious need of the Air Ministry to obtain Treasury approval for spending, but secondly, and more importantly, it shows the determination of the Air Ministry to produce more modern types of aircraft, and in larger numbers than before. The mention of the twin-engine aircraft is particularly revealing as it shows the willingness of the Air Ministry to include medium monoplane bombers within the makeup of RAF expansion. This justifies the rather substantial increase noted by Mr Self, as the Treasury were no doubt working with old aircraft type prices.

598 NA T161/836 – E.E. Bridges to A.H. Self, 10th September 1935
599 *Ibid.,* A.H. Self to E.E. Bridges, 1st November 1935
600 *Ibid.*

Scheme	MAF First Line Strength	Planned Annual Aircraft Production	Production in Previous Year
A (1934-39)	1,252	n/a	n/a
C (1935-37)	1,512	1,900	1,108 (1934)
F (1936-39)	1,736	2,667	1,807 (1935)
L (1938-40)	2,373	6,000	2,218 (1937)

Table 3 - British Air Rearmament Programmes, 1934-40[601]

In 1936 it was decided to increase the RAF expansion plans again, this time Scheme 'F' aimed to produce a force of 124 squadrons or a capacity of 1700 airframes per month.[602] Under this scheme some 24,200 aircraft would be required in the first year of a war.[603] This scheme, as is the case with the others, was not designed to give anything like war production. It was intended as a deterrent, and also to allow sufficient reserve for the first year of a war.[604] The final extension of the RAF came with Scheme 'L', which allowed for a significant increase in the number of first-line aircraft as well as shortening the time allowed for completion. It also made provisions for a more adequate reserve, introduced even more modern aircraft, and placed an emphasis on single seat fighters (namely the *Hurricane* and *Spitfire* types) raising their number by 45 per cent.[605] These expansion schemes led, particularly in the beginning, to several realisations. Firstly, that more production space would be required if these plans were to be completed in full and that more employees would be

601 Ritchie, *Industry and Air Power,* p. 42, the dates in the left hand column indicate the range in years of the programme.
602 NA AIR 20/3575 – R. Abraham to Air Member for Supply and Organisation (A.M.S.O), 15th January 1938
603 NA AIR 20/3575 – R. Abraham to A.M.S.O, 12th May 1937
604 NA AIR 20/3575 – R. Abraham to D.A.P, 15th March 1937
605 Ritchie, *Industry and Air Power,* p, 43

needed to fill said space. Secondly, it led to an ongoing investigation into the expected output of the industry in the first year of a European war.

CONCLUSIONS

Based on archival research this thesis provides a definitive account of British fighter development during the inter-war years. It emerged from two main issues. First, to some extent it has sought to refute certain declinist claims about the nature of the British inter-war military aircraft industry, but the thesis itself has been shaped largely by concerns that both declinist and revisionist history has oversimplified the nature of technological change and the place of such change in the story of inter-war industry and aircraft development.

As noted at the beginning of the thesis, the history of aviation technology has never gone far enough in explaining how technological change occurred. The contexts in which decisions were made are often glossed over or ignored altogether and the technology (the aircraft) is used for a different purpose. Work centred around industry only ever gives us an idea of how aircraft were manufactured, not how, or why, they were conceived, designed, tested, altered and then produced. Such histories will tend to use the aircraft itself as a symptom of some wider point being made such as an inefficient industrial framework, a governing body uninterested in developing the 'best' technology and so on.

Narrative histories focusing on the various innovations that led from the wooden biplane to the metal monoplane have already been done. What they miss is any sense at all of the complexity in technological change, how decisions and choices were made and the impact or influence of technology on the actors and institutions governing it. They are, by and large, determinist in nature with innovation following a linear and logical path and where alternatives are dismissed as being doomed from the outset. This thesis has, therefore, attempted to fill this gap and demonstrate that an awareness of Science and Technology Studies approaches can help to provide a fuller history of technological changes.

In the first place this is an exercise in the history of technology. As much as it is a history of a particular technology, it also seeks to make a contribution to Science and Technology Studies. I have not attempted to take a particular standpoint – at least not explicitly – such as the Strong Programme, though undoubtedly it has shaped my research agenda. In removing the need to make any sort of normative judgement as to the quality, efficiency or competence of the industry, government and so on, I have been able to focus on telling the story of a technological development as it happened.

The consequences of this for my analysis are largely positive as I have been able to factor into the story all kinds of evidence and thus I have not been hamstrung by attempting to build a particular case one way or another – the story is about *how* a technological change occurred, not an appraisal of that change. In instances where I have been able to make judgements, such as Trenchard's largely negative effect on technological progress I believe such claims are backed up convincingly by the evidence. I cannot say that this is an entirely symmetrical or objective history – such a thing is impossible – but in removing the need for normative judgements and the need to make a case for them I have been able to come much closer to doing that than I otherwise would have.

Methodology

A social constructionist position has been taken within this thesis and it has shaped the research design and the ways in which the data was collected and analysed. The central tenant as applied here is that knowledge, and the technology produced through that knowledge is socially constructed. That is, not dependent upon a single actor or institution, but rather, produced through interaction between an evolving network of different actors and institutions. A broad critical realist perspective is also present here centring around the notion that while knowledge and technology may be constructed socially, we must nevertheless be aware of very real material constraints to this process. Given the subject matter of this thesis, Pickersgill's example of critical realism is particularly apt:

> ...a plane, for instance, cannot just be talked into existence, but its components cannot be formed and fit together except through social action, nor can the cultural meanings ascribed to planes and flight be reduced to the artefacts of their technology.[606]

The research process did nothing but strengthen the view presented here that in order to adequately engage with the process of technological change we must focus on the idea that technology is a social product. While archive work was in this case the only option, the epistemological standpoints mentioned above helped to shape the research process and focus on certain types of data.

Archives

The research presented in this thesis was conducted in archives and libraries. Given the period in time that this thesis covers the consequences of this kind of research are self-evident but are nevertheless worth mentioning. In the first place other kinds of research (interviews, surveys, ethnography) were rendered impossible. The reliance on archival holdings presented many of the standard problems with research of this nature, namely that one can only interrogate a document to a certain point. It is not

[606] Pickersgill, M., (2009), *Ordering Disorderly Personalities: Co-Producing Antisocial Personality Disorder Through Policy, Science and Standards*, Ph.D. Thesis. University of Nottingham., p. 80

possible to ask questions of a document, or probe an interesting point that is only briefly mentioned. It arrives fully formed and carries with it all the assumptions, beliefs and prejudices of the author (or authors).

In the main, the holdings at the National Archives (Kew) were of the highest importance. While a concentration on documents of this nature may seem limiting at first, it quickly became apparent that there was a wide range of different types of source. Memoranda from different departments and circulated between different sections of the Air Ministry for comment were particularly useful. Collected correspondence between the Ministry and the industry was also incredibly valuable given the destruction of most company archives during the 1960s. It allowed as complete a look at the system of organisation of aircraft development as is possible to achieve. Broadly, the data collected fell into four main categories: official correspondence, executive memoranda, technical papers and testing literature.

The analysis of the data differed depending on the content. It was deemed necessary to begin with correspondence and memoranda. These documents offered the greatest insight into the shaping of policy, the thinking of participant actors about how aircraft ought to develop and how best to achieve those goals. Also, it was extremely useful for the identification of choice points and charting the process by which decisions and choices were made. The technical papers and testing literature on the other hand provided good insight into how aircraft were tested and more importantly how this information was appraised at the Air Ministry and by the industry.

'Declinism', 'Revisionism', and the British Military Aircraft Industry

One of the main aims of this research, and in large part the reason for its being was a dissatisfaction with the existing historiography and the declinist school in particular. It might be supposed that engaging directly with declinist historians like Correlli Barnett is engaging with a straw man. I would disagree with that view. Given the influence of such work on subsequent generations of historian and the pervasiveness of an inaccurate view of British science, technology and industry in this period it is vital to continue to demonstrate how inaccurate and misleading such claims are. Particularly, it would seem, with regards to aircraft. Similarly, the newer revisionist school seeks to address the balance by claiming the exact opposite – that there was no ‘failure’, only success. The primary concern here is not the discussion about industries or relative vs. absolute economic decline, but their treatment of the technology.

If one looks hard enough it is possible to find technologies (and the stories of their development) that support any wider assertion as to the health of the industry or the competence of those working within it. Claims about the ill health of the industry and its technology might cite the fact that F.7/30 failed to produce a decent monoplane fighter, or worse still, that the winner was a perfectly conventional biplane. Certainly that is David Divine’s discourse, but again, there is no sense at all of what was really going on, merely what the result of the specification was and that the result was not good enough. For example, his assessment of F.7/30 is simply that “four years had been lost over the absurdities of [it]”.[607] In fact, his assertion that the Air Ministry were only interested in developing a monoplane from 1933 is incorrect as F.7/30 (formulated between 1928 and 1929) strongly suggested exploring the monoplane and indeed that such designs would be preferable.

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[607] David Divine, *The Broken Wing - A Study in the British Exercise of Air Power* (Essex: Cheltenham Press, 1966). p. 182

For revisionists like Edgerton trying to rectify what he saw as highly misleading thinking it was found necessary to construct an entirely opposite case in which the British aeronautical endeavour was consistently healthy and well managed much in keeping with his position on British industrial, scientific and technological status. On balance, the revisionist account is more accurate, however, the same problems persist within this literature. The technology is merely a symptom of a healthy industry and explanations about its development are largely ignored. This research has highlighted weaknesses within the existing historiography and offers an alternative to both schools' treatment of technology and its development by demonstrating that their conclusions are based on partial or misleading conceptions of technological development generally, and of the nature of military aircraft procurement in particular.

The metal monoplane of 1939 was more than a decade in the making. Excluding the switch from wood to metal which was completed by 1925 and widely utilised in biplane designs, the 1939 fighter relied upon a host of incremental and some radical changes to evolve. The pace at which these changes took place was governed largely by how the idea of an air war was conceived and how those ideas changed over time. Fighter aircraft were not a priority throughout the 1920s. Trenchard's doctrine of a strong bomber offensive made sure that fighters could only really be used for home defence and even then, in his view, they would achieve very little by way of protection (they existed ostensibly to create a positive effect on national morale). This is why we see that in the late 1920s, when F.7/30 was beginning to be formulated, discussions of the suitability of monoplanes and alternative conceptions of the fighter aircraft took place at a relatively low level within the Air Ministry, and it was not until 1930 when Trenchard left that more progressive discussions about monoplanes took place at a higher level.

On the technical side there were various obstacles that needed to be overcome. Retractable landing gear was identified as being crucial if the monoplane was to be worthwhile and present a truly better alternative to the biplane. At first they were deemed too heavy to be of any real use as the added weight negated any aerodynamic benefit from removing a fixed undercarriage. As engine power increased the parasitic drag of a fixed undercarriage became worse and worse and there came a point where retracting it, despite the increase in weight, produced large gains in performance. Engines themselves were developed differently to the rest of the aircraft, but the development of aeronautical technology as a whole depended a great deal on the increase in power and the altitudes at which engines could safely operate.

The Schneider Trophy is another example of a significant part of the story that is given cursory treatment in the existing historiography. For Barnett, Britain's eventual outright victory was a "shop window triumph". For Edgerton, the Schneider aircraft demonstrate the difficulty of using speed and structure as the only indices to describe an aircraft. However, neither look beyond the final aircraft itself. The Trophy was an incredibly useful endeavour for the British aeronautical establishment. It allowed for relatively risk-free innovation. Though initially offering natural benefits over the monoplane, one reason the biplane persisted for as long as it did as the dominant design in military aircraft was the risk (much higher during the 1920s and early 1930s) of failure and the correspondingly high rewards for success. As such, designs were tendered which designers believed offered the best chance of being accepted.

The switch to the monoplane in racing aircraft around 1924 (almost a decade before such successful designs saw service with the RAF) resulted from two things. Firstly, there was the realisation that Curtiss had almost perfected the racing biplane and as Mitchell saw it, further progress along such lines would be painstakingly slow. The monoplane was fresh ground, and the Trophy allowed for highly concentrated aerodynamic research to take place largely funded by the Air Ministry. The reward for success in the competition was mostly an increase in reputation and there was little in the way of direct financial gain. However, the knowledge gained through the research conducted into Schneider aircraft was invaluable. The competition "proved" the superiority of the monoplane for performance and the research conducted in aerodynamics would be crucial in years to come. All of this is ignored or missed in the conventional history. In terms of consensus building the Supermarine *'S'* series of Schneider racers provided empirical proof to everyone watching them that the monoplane was the superior performance aircraft. Translating that into a functional military machine was the difficulty and would not be realised until the *Spitfire* and *Hurricane* of 1936.

More significantly, it should be clear at this point that looking more closely at the complexities involved in aircraft conception, design, construction and development offer a sharp counterpoint for the often simplified and misleading histories produced thus far. Studies centred around an economic, business or industrial standpoint cannot provide any sort of meaningful analysis of technology. Using the technology as a convenient symptom of their wider analyses cannot be considered accurate unless the technology is treated properly and this means looking into the social aspects of its creation and change such as the different and varying social structures (Air Ministry, SBAC or industry) that evolved over the inter-war years. It also means looking at how research was conducted and how the results of that research was utilised.

This is not meant as a contribution to the literature of inter-war business and industrial history, although it does contribute to it. In engaging with it, however, I have been able to draw out some weaknesses and offer an alternative conception of the state of British military aircraft in the period. How they were conceived, developed, manufactured and used. Perhaps most importantly is the fact that by utilising concepts from the field of Science and Technology Studies, I have been able to provide a deeper understanding of how need and requirement were formulated and a real insight into how the whole system of aircraft procurement worked.

The discourse of declinist historians has been largely debunked by the work of the newer revisionist school, though not without limitations. As we have noted, both treat the technology in a somewhat throwaway manner. However, while the revisionists present a more accurate picture of the socio-technical system involved in developing military aircraft, declinist appraisals of the technology and its system of production are largely without merit. There are glaring inaccuracies and the use of highly selective sources to back up arguments made for the delay in technological development. For example, in buttressing his assertion that innovation of smaller component technologies was non-existent in Britain, Barnett quotes Clement Attlee (then leader of the opposition) speaking in 1938:

> *Why is [it] that despite the vast sums of money spent on research at Farnborough and elsewhere, all the principle inventions seem to come from abroad, e.g., the retractable undercarriage, variable pitch screw, etc etc….*[608]

[608] Barnett, Audit, p. 129

We have seen, however, that work on the retractable undercarriage commenced as early as the mid-1920s through George Dowty, and the retractable mechanisms used by Supermarine and Hawker for the *Spitfire* and *Hurricane* were developed 'in-house'. Variable pitch screws, heating systems for guns working at altitude, ducted radiators, the Handley Page 'slot' wing were all developed at firms within the British industry. This is not to say, of course, that many innovations did not come from abroad. The wet-sleeve monobloc engine came from the United States, metal construction was truly pioneered and implemented with great success in Germany and some of the finest navigational components also came from there.

For declinist historians the picture painted of British industry and its technical ability is enough to suggest that technological failure was commonplace, that innovation was stagnant and that management of the socio-technical system was flawed. However, if we work backwards, taking the latter as our starting point and appraise it properly a different picture emerges. It has been made clear that there were instances of success and failure as well as examples of mismanagement and sensible, creative courses of action identified and swiftly taken.

STS and Historiography

It is argued here that based on the case made in this thesis the use of theoretical frameworks and concepts from STS can be highly beneficial to the historical study of technological change. The limited, one-sided appraisal of technology attributed to the existing historiography can be radically opened up when viewed through an STS lens. Fundamentally, the history of technology can benefit from such a synthesis through an awareness of complexity in technological change and its dependence on many different, intertwined contextual factors.

STS as a discipline demands that we be aware of the specific contexts within which a technology is created and develops. It asks that we treat each development symmetrically, that each development be explained in the same terms regardless of success or failure. Declinist literature regarding the inter-war aviation industry and its technology consistently compare some approximation of what happened with what they believed should have happened. For example, monoplane fighters as they existed in the RAF in 1939 should, for them, have been present from the early 1930s because that is what other nations (ostensibly Germany and the United States) were able to achieve.

David Divine has criticised specification F.7/30 and its failure to produce a quality monoplane for the service. His critique is based on a misreading of the specification and the mistaken belief that the Air Ministry were hostile to the idea of a monoplane. The Air Ministry is seen as being even further at fault because it was a relatively conventional biplane that was chosen, never mind its quality and the fact that the Gloster *Gladiator* saw service well into the Second World War. His treatment of the technology is cursory and while keen to judge the specification, its results and the industry, he makes no attempt to understand the context in which the events took place.

An STS approach also requires that we dispense with normative judgements appraising the outcome of events as 'good' or 'bad'. Furthermore, it is argued here that even without an STS centred approach to technological history an appraisal of the pace of technological change in terms of 'good' and 'bad' is largely ineffectual as it does not add anything to our understanding of it. We may say that the management of a particular innovation was weakened by the personal prejudices of some within the Air Ministry or that the influence of a particular actor was a significant factor in the success of another. However, surely we cannot dismiss an entire specification and its outcome as an 'absurdity' simply because Germany had monoplanes and so anything less than that must be deemed a failure.

Perhaps the most useful aspect of an STS perspective as applied to the history of technology is that it allows us to be highly flexible in terms of the collection and analysis of data. Our objective was to utilise concepts from STS to construct a series of stories designed to highlight the particularly complex nature of technological change. The concepts and theories chosen demanded that in the first instance the selection of data focused upon anything that had a bearing on technical development at any point on the spectrum (for example, engineers, designers, scientists and policymakers). The use of Hughes' concept of the socio-technical system aided in mapping out these points, determining their relative influence on the creation, development and shaping of aircraft technology.

But why is an STS centred approach any better than the standard declinist/revisionist discourse that has gone before? Surely it is just a different approach to a different set of questions. It is argued here that a key component of both schools of thought is the use of technology to support arguments made about the management of technological change and the pace at which it was completed but that incomplete, partial or misleading discussions about these particular technologies do something quite opposite when viewed under an STS framework.

We will turn now to Science and Technology Studies, the concepts used within this thesis to shape the research and analysis of data, the consequences of its use and how in so doing a more complete history of technology and the system surrounding its development may be achieved.

Presumptive Anomalies, Socio-Technical Systems and Consensus Building

The emergence of new technologies can spur on or restrict the development of others very often in entirely unexpected ways. A good example is that of the *Merlin* aero-engine. By allowing for a significant increase in the operational altitude of aircraft they were used in, a new technological 'fix' was required to prevent the guns in the *Spitfire* freezing over and becoming unusable. There is enormous value in theoretical perspectives which allow for complexity and which can take account of anomalies. Theories advanced by Hughes and Constant are perhaps the best examples of this. The use of theory in this thesis has been largely implicit throughout the main story. The concepts discussed in the introductory section are those that guided the research process and subsequent analysis.

One of the major findings of this thesis is that of consensus building. In both of the widespread switches from wood to metal and the multi-wing format to the monoplane, a consensus amongst the aviation community was required in order to affect such changes. However, consensus alone was not enough. The switch to metal required not only the widespread belief that it was correct, but also the technological capacity to be able to affect such a change, not to mention less immediately obvious requirements such as a corps of metal workers to keep RAF aircraft in service. The change to the monoplane, too, required more than just the widely held belief that the monoplane was superior for performance. The F.7/30 specification demonstrates that even while monoplane racers were setting world speed records every couple of years, transferring that knowledge to a practical, working fighter aircraft was still beyond even the most skilled designers.

These examples precisely reflect the core message of this thesis. That technological change is messy, disorganised and more often than not, it is the result of many factors aligning themselves over time. The element most responsible for widespread change, however, is consensus. It is the widely held belief in the potential of technology or innovation that sustains developmental work on a wider scale in the face of setbacks or dissenting views. It has been shown that much of the criticism levelled at the Air Ministry and industry (backwards looking and technically inept) has been unwarranted with F.7/30 itself proving that even in 1929 a single-seat monoplane fighter was sought after.

The work of Hughes and Constant has been particularly important in bringing together both of these major stories. Each aided in the identification of important elements in these changes. The switch to metal in the United States has been characterised as the product of an 'ideology of progress' – that metal was the future, wood the past, and spurred on by developments in Germany and a desire to not be 'left behind'. The example of the United Kingdom is directly at odds with this assessment. We have seen that work by Hugo Junkers was a definite catalyst in the sense that it proved a metal aircraft could fly. However, the practical benefits of a metal aircraft took years to be realised in Britain.

Constant's concept of the presumptive anomaly is most clearly seen in the first movements towards metal construction. Both A. P. Thurston and John North believed that metal could do a better job than wood as a material for manufacturing aircraft in the future. The development of metal as a viable choice for aircraft construction required a consensus between designers, engineers, pilots and government and it took time to form. It will be remembered that a presumptive anomaly occurs when advances in science or engineering 'imply future difficulty for the existing system or the possibility of a new one'. The emphasis placed on practitioners maintains that revolution can only occur when a significant portion of the relevant community moves to a new paradigm and begins work on a 'new normal technology'.

One of the major characteristics of technological development throughout the period is the creation of consensus around a new technology, design or practice. Setbacks were common and work was required to sustain new developments. The most influential were perhaps those involving people and prejudice rather than technological limitation. While belief in an alternative was growing technical problems could be overcome, money could be directed to research, designers had faith in what they were doing, and an aircraft firm believed they would eventually make money from the development and use of a new technology. The major problems came from people (specifically decision makers) and Hugh Trenchard is the best example of this.

Thomas Hughes' reverse salient concept neatly reflects the development of aircraft technology. The progress of a technological endeavour is held up by pockets of resistance that must be eliminated by bringing extra resources to bear on those particular problems. I believe that this thesis shows a reverse salient can be social as well as technical in so far as certain instances of delay can be attributed to poor management, or the prejudices of certain actors towards a technology (Trenchard's suspicion of metal, his refusal to support the technically superior Fairey *Fox*, or Dowding's apparent lack of support for retractable gear are examples). These salients needed to be eliminated by a contrary weight of opinion.

Technologically, however, there were a great many more salients to be overcome. Supermarine's F.7/30 effort (the *224)* revealed a host of problems in translating design and construction from successful racing seaplanes to a military fighter monoplane. The wings were too thick, it had a fixed undercarriage, the engine was not suitable for use with monoplanes and it had an open canopy. Thus, reverse salients occur at all levels of technical change: within a design, within a firm, industry or governing body.

The Schneider Trophy provides good insight into the gradual/radical process of technical change. In view of the fact that performance was the sole aim the designers' job was relatively simple. Rather than attempting to balance several, what might be termed 'macro' economies – form, weight, rate-of-climb, top speed, useful load and so on – he was tasked with balancing only those necessary to achieve optimum performance, i.e., speed. Initially, the race was contested with flying boats the aerodynamics of which were refined over the years, the engine power increasing each time. This was superseded by the more radical change to the seaplane (an aircraft that floated rather than a boat which flew). Again, incremental improvements in aerodynamics and power output developed the biplane racer paradigm. The final radical shift came in the form of the monoplane racer first developed by Mitchell at Supermarine. Thereafter, all that could be done in terms of development was marrying increasing power output to refined aerodynamics.

Hughes' systems and Frank Geels co-evolution emphasise the interplay of components within a 'socio-technical system'. Do they go far enough? Do they explain enough? What they do particularly well is to provide a framework for the analysis of technological change. Each approach (for example ANT, SCOT or STS) provides such a framework. The issue for many is about how well they do it. As I set out in the theoretical section, explanations relying upon one approach are bound to be limited in some way or other. Technological change is the result of painstakingly gradual progress punctuated by radical innovation. Choices are made. It is difficult to imagine that one theoretical approach could provide an explanatory framework for every instance of technological change. What is clear, however, is that each has highly valuable insights, concepts, or tools. Specifically related to this thesis are those concepts that provide flexibility.

Technological Paradigms, Trajectories and Technological Transitions

When discussing technological paradigms it must be made clear which definition one is using: the paradigmatic design (exemplar), or the 'entire constellation of beliefs', a shared vision for a technology? This thesis has looked at both, although neither arrives fully formed. In the first instance, a paradigmatic design is the result of both gradual work (research conducted in aerodynamics was often painstakingly slow) and radical shifts (the movement to the monoplane and its subsequent stabilisation). In the second, a shared vision is the result of gradual work done by those with the vision and drive to see it through. Thus, the creation of consensus in the case of metal relied upon authoritative actors (Junkers, North and Thurston) engaging in a process of 'system building'. Not so much in the way of Thomas Hughes' system builders (Edison) – for North and Thurston it was not in the first instance an economic gain they chose to pursue but a technical one.

Both paradigmatic designs and a shared belief amongst a community are, therefore, the result of conscientious 'system building'. However, the wood-metal example is distinct from the search for a monoplane. The case of metal relied upon an initial belief held by very few given momentum by constructing a convincing case for the widespread use of the material, this was followed by the slow process of refinement of new methods of design and construction. The change itself was relatively straightforward once the Air Ministry took the decision to switch in 1925. Convincing the Air Ministry was the critical point because once it was persuaded of the need for such a change any alternative to metal was removed. Put bluntly, designs in anything other than metal would not be considered for purchase.

The move to the monoplane happened differently. First World War experience in both monoplane and biplane fighters had done nothing at all to convince designers that, at that time, the monoplane offered any advantage in performance. The primary driver in the move to the monoplane was ever-increasing engine power and again, the Schneider Trophy provides the best example. The Curtiss CR-3 biplane which won both first and second place in the 1922 race convinced Reginald Mitchell to switch to the monoplane by realising that developing the biplane paradigm further would be far more difficult that attempting to utilise a monoplane structure.

And yet, the biplane continued to dominate British military aircraft for more than a decade. In sharp contrast to the switch from wood to metal, there was no direct opposition to the idea of the monoplane. In terms of performance there was no doubt that it was superior. However, the expertise in design and construction lay firmly with the biplane, and while it was the 'safe' choice for designers (at least throughout the 1920s) the shift to monoplanes required more. Thus, the development of the paradigmatic design as it stood in 1939 required two major shifts (metal construction and monoplane form) and a host of gradual ones. The constellation of beliefs evolved over time, and it is perhaps in this sense that the idea of consensus building is most useful.

The idea of technological paradigm as an exemplar used as a basis for future work is useful in that it allows for a different conception of technological change. The Curtiss *CR-3* racing biplane was possessed of exceptionally clean aerodynamics and in order to make significant gains in performance designers (particularly Mitchell at Supermarine) were effectively forced to look to a major change in design. His subsequent monoplane, the *S 4*, provided not just the basis for future work in racing seaplanes at Supermarine, but the United States and Italy as well.

However, the development of a paradigmatic design is largely dependent upon the influence of the community of practitioners designing it. This is the constellation of beliefs – the development of a particular way of working and a shared view of what was the 'standard' design. How they got from one to the other has been the basis of this thesis and within it I have shown how it complex it was. The factors influencing change were social and technological, they operated at different levels (top down: Ministry, industry, firm, designer) and across a number of periods (the 'Lean Years', the early movements towards rearmament in the latter 1920s, the attempt to develop a world beating fighter in the early 1930s and so on).

Implications for Future Work

I believe the biggest contribution that this research makes is to the history of aviation and even to some extent to histories of business and industry. One of the major limitations of the declinist and revisionist histories of the industry is that in many ways they are simply not accurate. Gaining a greater understanding of the technology and the way it developed within an industrial or business framework must surely have enormous value. Barnett, for example, reduced the Schneider Trophy success to a 'shop window triumph' and yet we have seen just how important this contest was for the development of British aircraft. How different might his work have been if he had treated the technology and its development with any degree of care? Thus, the final proposition of this thesis is that the history of technology can go further by utilising analysis from Science and Technology Studies.

Bibliography and Sources

ORIGINAL SOURCES CITED

THE NATIONAL ARCHIVES, KEW

NA 23/4026	AIR 1/17/15/1/84	AIR 1/2100/207/28/11
AIR 1/2100/207/28/12	AIR 1/702/27/3/736	AIR 1/716/27/19/26
AIR 10/494	AIR 19/126	AIR 19/92
AIR 2/1208	AIR 2/1213	AIR 2/1303
AIR 2/1322	AIR 2/1323	AIR 2/2741
AIR 2/2815	AIR 2/2850	AIR 2/605
AIR 2/639	AIR 2/848	AIR 20/3575
AIR 20/68	AIR 20/70	AIR 5/1368
AIR 5/328	AIR 5/537	AIR 5/564
AIR 6/22	AIR 8/67	AIR 8/73
AVIA 10/90	AVIA 46/119	AVIA 6/7065
AVIA 8/166	DSIR 23/1510	DSIR 23/1525
DSIR 23/1558	DSIR 23/1987	DSIR 23/2074
DSIR 23/2214	DSIR 23/2248	DSIR 23/2340
DSIR 23/3887	DSIR 23/5362	DSIR 23/9679
DSIR 36/4223	T161/836	T 28/207

PATENT AND REPORTS

Parker, H. F., NACA, Report 77, *The Parker Variable Camber Wing*, (1920),

Lachmann, Gustav, NACA, Technical Notes No. 71, *Experiments with Slotted Wings*, November 1921

Handley Page, Frederick., *Wing and Similar Member of Aircraft*, U.S. Patent 1,353,666, Filed July 6, 1920. Patented Sept. 21, 1920.

NACA, Technical Notes, No. 100, *Theory of the Slotted Wing*, Lecture by Albert Betz, 1922

Hill, G. T. R., *Control Surfaces for Aeroplanes,* U.S. Patent 1,600,671, Filed March 10, 1926. Patented September 21, 1926

PUBLISHED MATERIALS

Abernathy, William J., and James M. Utterback. "Patterns of Innovation in Technology." *Technology Review* 80, no. 7 (1978): 40-47.

Ackroyd, J. A. D. "Sir George Cayley, the Father of Aeronautics, Part 1: The Invention of the Aeroplane." *Notes and Records of the Royal Society of London* 56, no. 2 (2002): 167-81.

Andrews, J. O. "The Single Seater Fighter Tactical Unit for Home Defence." *Royal United Service Institution* 77 (1932): 382-84.

———. "The Strategic Role of Air Forces." *Royal United Service Institution* 76 (1931): 740-43.

Angelucci, Enzo, and Paolo Matricardi. *World Aircraft, 1918-1935*. Milan: BCA, 1977.

Anon. "The 470 H.P. Curtiss D.12 Engine." *Flight* Vol. XVI, No. 17 (1924): 232-33.

———. "Air Ministry Acquire Short "Silver Streak"." *Flight* XIII, no. 8 (1921): 127.

———. "Another All-British Biplane - Details of the De Havilland Machine." *Flight* II, no. 67 (1910): 266-8.

———. "Engines for Aeroplanes." *Flight* Vol. 1 No. 3 (1909): 33-35.

———. "Engines for Aeroplanes Continued." *Flight* Vol. 1 No. 4 (1909): 46-49.

———. "The First Paris Aeronautical Salon." *Flight* Vol. 1 No. 1 (January 2 1909): 6-11.

———. "Milestones - the Vickers Machines." *Flight* Vol. XI No. 24 (1919): 760-69.

———. "The N.E.C. Two-Stroke Flight Engine." *Flight* Vol. 2 No. 52 (1910): 1052-53.

———. "The Position of the Aeronautic Industry." *Flight* Vol. 1 No. 2 (1909): 17-18.

Anon. "600 Vacancies as Raf Aircraft Apprentices." *Flight* XIX, no. 29 (July 21, 1927 1927): 506.

———. "The Boulton and Paul "Bolton" (P. 15)." *Flight* XIV, no. 40 (October 5, 1922 1922): 571-72.

———. "British Aircraft." *Flight* XXIV, no. 47 (1932): 1067-83.

———. "The Building of a Flyer." *Flight* 1, no. 23 (1909): 332-35.

———. "Editorial Comment." *Flight* XX, no. 14 (5th April, 1928 1928): 223-24.

———. *N.P.L. History Highlights*. The National Physical Laboratory2008.

———. "Retractable Undercarriages." *Flight* XXVI, no. 1330 (1934): 600.

———. "The Schneider Cup Seaplane Race." *Flight* XVII, no. 39 (September 24 1925): 609-13.

Baldwin, Stanley. "Mr Baldwin on Aerial Warfare - a Fear for the Future." *The Times*, 11th November 1932, 7.

Barnett, Correlli. *The Audit of War - the Illusion and Reality of Britain as a Great Nation*. London: Macmillan, 1986.

Bazzocchi, Ermanno. "Technical Aspects of the Schneider Trophy and the World Speed Record for Seaplanes." *The Journal of the Royal Aeronautical Society* LXXVI (1972): 65-82.

Bijker, Weibe E., and Trevor J. Pinch. "Scot Answers, Other Questions." *Technology and Culture* 43, no. 3 (2002): 361-69.

Bijker, Wiebe E., and Trevor J. Pinch. "The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other." *Social Studies of Science* 14 (1984): 399-441.
Block, E. B. *Above the Civil War: The Story of Thaddeus Lowe, Balloonist, Inventor, Railway Builder*. Howell-North1966.
Bloor, David. *The Enigma of the Aerofoil - Rival Theories in Aerodynamics, 1909-1930*. London: University of Chicago Press, 2011.
———. *Knowledge and Social Imagery*. Chicago1991.
Booth, Ken. "The Ten-Year Rule: An Unfinished Debate." *Royal United Service Institution* 116 (1971): 58-62.
Brew, A. *Boulton & Paul Aircraft since 1915* London: Putnam, 1993.
Brooke-Popham, Robert. "Aeroplanes in Tropical Climates." *The Journal of the Royal Aeronautical Society* Vol. XXV, no. No. 131 (1921): 563-80.
Brooks, P. M. *Zeppelin: Rigid Airships, 1893-1940*. Smithsonian1992.
Buchanan, R. A. "Theory and Narrative in the History of Technology." *Technology and Culture* 32, no. 2 (1991): 365-76.
Carr, E. H. *What Is History?* 2nd ed. Palgrave Macmillan2001.
Charles Vivian, E. *A History of Aeronautics*. New York1921.
Clayton, Nick. "Scot: Does It Answer?". *Technology and Culture* 43, no. 2 (2002): 351-60.
Cochran, Thomas C. "Theory and History." *The Journal of Economic History* 3 (1943): 27-32.
Constant, Edward W. "The Social Locus of Technological Practice: Community, System, or Organization?". In *The Social Construcion of Technological Systems: New Directions in the Sociology and History of Technology*, edited by W. E. Bijker, T. P. Hughes and T. Pinch. 223-42: MIT Press, 1987.
Constant II, Edward W. "A Model for Technological Change Applied to the Turbojet Revolution." *Technology and Culture* 14, no. 4 (1973): 553-72.
Divine, David. *The Broken Wing - a Study in the British Exercise of Air Power*. Essex: Cheltenham Press, 1966.
Dosi, Giovanni. "Technological Paradigms and Technological Trajectories - a Suggested Interpretation of the Determinants and Directions of Technical Change." *Research Policy* 11 (1982 1982): 147-62.
Douhet, Giulio. *The Command of the Air*. London: Faber & Faber, 1943.
Dowty, G. H. "Retractable Undercarriages." *Journal of the Royal Aeronautical Society* XL, no. I (1936): 249-303.
———. "Undercarriage Developments." *Journal of the Royal Aeronautical Society* XXXIV (1930): 170-83.
Edgerton, David. "The Decline of Declinism." *The Business History Review* 71, no. 2 (1997): 201-06.
———. *England and the Aeroplane - an Essay on a Militant and Technological Nation*. Manchester: Macmillan, 1991.
———. *Science, Technology, and the British Industrial 'Decline'*. Cambridge: Cambridge University Press, 1996.
———. *Warfare State - Britain, 1920-1970*. Cambridge: Cambridge University Press, 2006.
Ellam, C. "Developments in Aircraft Landing Gear, 1900-1939." *Transactions of the Newcomen Society* 55 (1983-1984): 48-51.
Fairey, C. R. "The Future of Aeroplane Design for the Services." *Royal United Service Institution Journal* 76 (1931): 563-80.

Farren, W. S. "Monoplane or Biplane." *Journal of the Royal Aeronautical Society* XXXIII, no. Pt. II (1929): 490-540.

Fearon, Peter. "The British Airframe Industry and the State, 1918-1935." *The Economic History Review* 27, no. 2 (1974): 236-51.

———. "The Formative Years of the British Aircraft Industry, 1913-1924." *Business History Review* 43, no. 4 (1969): 476-95.

———. "The Growth of Aviation in Britain." *Journal of Contemporary History* 20, no. 1 (1985): 21-40.

Ferris, John. "Fighter Defence before Fighter Command: The Rise of Strategic Air Defence in Great Britain, 1917-1934." *The Journal of Military History* 63, no. 4 (1999): 845-84.

Ferris, John R. "The Air Force Brats' View of History: Recent Writing and the Royal Air Force, 1918-1960." *The International History Review* 20, no. 1 (1998): 118-43.

Fozard, J. W. *Sydney Camm and the Hurricane: Perspectives on the Master Fighter Designer and His Finest Achievement*. Washington D.C.: Smithsonian Institution Press, 1991.

Gardner, Richard, and David Wilson. "Making It Real." *Aeroplane* November (2008): 26-29.

Geels, Frank W. "Co-Evolutionary and Multi-Level Dynamics in Transitions: The Transformation of Aviation Systems and the Shift from Propeller to Turbojet, 1930-1970." *Technovation* 26 (2006): 999-1016.

Gibbs-Smith, C. H. *Aviation - an Historical Survey*. Second ed. London: HMSO, 1985.

———. *The Invention of the Aeroplane, 1799-1909*. London: Faber & Faber, 1966.

———. *The Rebirth of European Aviation, 1902-1908*. London: HMSO, 1974.

———. "Sir George Cayley: 'Father of Aerial Navigation', 1773-1857." *Notes and Records of the Royal Society of London* 17, no. 1 (1962): 36-56.

———. *The Wright Brothers - a Brief Account of Their Work, 1899-1911*. London: HMSO, 1987.

Goddard, R. V. "The Development of Aircraft and Its Influence on Air Operations." *Royal United Service Institution* 79 (1934): 449-57.

Goldthorpe, J. H. "The Use of History in Sociology: Reflections on Some Recent Tendencies." *British Journal of Sociology* 42 (1981): 211-30.

Gollin, Alfred. "The Mystery of Lord Haldane and Early British Military Aviation." *Albion: A Quarterly Journal Concerned with British Studies* 11, no. 1 (1979): 46-65.

———. "The Wright Brothers and the British Authorities, 1902-1909." *The English Historical Review* 95, no. 375 (1980): 293-320.

Grattan, Robert F. *The Origins of Air War*. London: I. B. Taurus, 2009.

Gunston, Bill. *World Encyclopedia of Aero Engines*. London1986.

———. *World Encyclopedia of Aero Engines - from the Pioneers to the Present Day*. Fifth ed.: Sutton Publishing, 2006.

Haldane, Richard Burdon. *An Autobiography*. London: Hodder and Stoughton, 1929.

Handley Page, Frederick. "The Handley Page Wing." *Journal of the Royal Aeronautical Society* XXV, no. 126 (1921): 263-89.

Hannah, Leslie. "Afterthoughts." *Business and Economic History* 24 (1995): 246-62.

Harrison, Robert. "History and Sociology." In *Making History: An Introduction to the History and Practices of a Discipline*, edited by Peter Lambert and Phillipp Schofield. 138-49. Routledge, 2004.

Harte, N. B., ed. *The Study of Economic History*. Cass, 1971.
Hassell, Patrick. "Advances in Aerodynamics." In *Biplane to Monoplane - Aircraft Development, 1919-1939*, edited by Phillip Jarrett. London: Putnam, 1997.
Higgs, Henry. "The Geddes Report and the Budget." *The Economic Journal* 32, no. 126 (1922): 251-64.
Higham, Robin. "Government, Companies, and National Defence: British Aeronautical Experiment, 1918-1945 as the Basis for a Broad Hypothesis ". *The Business History Review* 39, no. 3 (1965): 323-47.
Hoff, N. J. "A Short History of the Development of Airplane Structures." *American Scientist* 34, no. 2 & 3 (1946).
Hughes, Thomas P. "Edison and the Electric Light." In *The Social Shaping of Technology*, edited by Judy Wajcman and Donald MacKenzie. 50-63. Open University Press, 2003.
———. "The Evolution of Large Technological Systems." In *The Social Construction of Technological Systems*, edited by Weibe E. Bijker and Trevor Pinch. 51-82.
———. *Networks of Power - Electrification in Western Society, 1880-1930*. Johns Hopkins1983.
———. "The Seamless Web: Technology, Science, Etcetera Etcetera." *Social Studies of Science* 16, no. 2 (1986): 281-92.
Hyde, H. Montgomery. *British Air Policy between the Wars, 1918-1939*. London: Heinemann, 1976.
Jackson, A. J. *Blackburn Aircraft since 1909*. London: Putnam, 1968.
Jackson, Robert. *Army Wings: A History of Army Air Observation Flying, 1914-1960*. Pen and Sword Aviation2006.
James, D. N. *Glostor Aircraft since 1917*. London: Putnam, 1968.
Jane, F. T. *Jane's All the World's Aircraft*. London1913.
Jarrett, Philip. "October 16, 1908 - Britain's First Powered Flight." *Aeroplane* November (2008): 22-25.
Jarrett, Phillip, ed. *Biplane to Monoplane - Aircraft Development, 1919-1939*. Putnam, 1997.
Jordanova, Ludmilla. *History in Practice*. Hodder2006.
Junkers, Hugo. "Metal Aeroplane Construction." *The Journal of the Royal Aeronautical Society* Vol. XXVII (1923): 406-49.
Kuhn, Thomas. *The Structure of Scientific Revolutions*. Third ed. Chicago 1996.
Law, John. "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion." In *The Social Construction of Technological Systems*, edited by Weibe E. Bijker and Trevor Pinch. 111-34: MIT Press.
———. "Theory and Narrative in the History of Technology: Response." *Technology and Culture* 32, no. 2 (1991): 377-84.
Lewis, Peter. *The British Bomber since 1914*. London: Putnam, 1967.
———. *The British Fighter since 1912 - Fifty Years of Design and Development*. London: Putnam, 1967.
Mackay, C. J. "The Influence in the Future of Aircraft Upon Problems of Imperial Defence." *Royal United Service Institution Journal* 67 (1922): 274-310.
MacKenzie, Donald. *Inventing Accuracy - a Historical Sociology of Nuclear Missile Guidance* MIT Press1990.
MacKenzie, Donald, and Judy Wajcman, eds. *The Social Shaping of Technology*. Open University Press, 2003.

MacLeod, R., and K. Andrews. "The Committee of Civil Research - Scientific Advice for Economic Development, 1925-1930." *Minerva* 7 (1969): 680-705.
Mason, F. K. *The British Fighter since 1912*. London: Putnam, 1992.
Mayo, Major R. H. "The Development of High Speed Aircraft." *Journal of the Royal Aeronautical Society* XXVIII, no. 159 (1924): 158-88.
McDonald, Andrew. "The Geddes Committee and the Formulation of Public Expenditure Policy, 1921-1922." *The Historical Journal* 32, no. 3 (1989): 643-74.
McFarland, Marvin. "When the Airplane Was a Military Secret." *The Air Power Historian* 2, no. 4 (1955).
Meekcoms, K. J., and E. B. Morgan. *The British Aircraft Specifications File, 1920-1949*. Tonbridge: Air Britain, 1994.
Meilinger, Phillip S. "Trenchard and "Morale Bombing": The Evolution of Royal Air Force Doctrine before World War Two." *The Journal of Military History* 60 (1996): 243-70.
Mills, C. W. "Uses of History." In *The Sociological Imagination*, edited by C. W. Mills. 143-64. Oxford, 2000.
Mitchell, Gordon. *Schooldays to Spitfire*. Stroud: Tempus, 2006.
Mitchell, Reginald J. "Design of the S. 5." *Aeronautical Research Committee* Reports and Memoranda No. 1300 (1931): 296-311.
———. "Racing Seaplanes and Their Influence on Design." *Aeronautical Engineering Supplement, The Aeroplane* (25th December 1929).
Mitchell, William L. *Winged Defence: The Development and Possibilities of Modern Air Power, Economic and Military*. New York: Putnam, 1925.
Moseley, Russell. "Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years." *Notes and Records of the Royal Society* 35, no. 2 (1980): 167-93.
North, John D. "The Case for Metal Construction." *The Journal of the Royal Aeronautical Society* Vol. XXVII (1923): 3-25.
———. "The Case for Metal Construction." *Flight* XIV, no. 722 (1922): 632-33.
Omissi, David. *Air Power and Colonial Control - the Royal Air Force, 1919-1939*. Manchester: Manchester University Press, 1990.
Overy, Richard. *The Air War*. New York1980.
———. "The German Pre-War Aircraft Production Plans: November 1936-April 1939." *The English Historical Review* 90, no. 375 (1975).
Postan, M. M. . *British War Production*. HMSO: London, 1952.
Prentice, J.D. "Aircraft in War in Ten Years Time." *Royal United Service Institution Journal* 74 (Feb. 1929 1929): 705-13.
Price, Alfred. "Spitfire Prototype and Mark I." *Aeroplane*, no. March (2006).
———. *The Spitfire Story*. Second ed. London: Arms and Armour, 1995.
Quill, Jeffrey. *Spitfire - a Test Pilot's Story*. Crecy, 1996.
Riding, Richard. "The Sparrow." *Aeroplane Monthly* 13, no. 498 (1985).
Ritchie, Sebastian. *Industry and Air Power - the Expansion of British Aircraft Production, 1935-1941*. London: Cass, 1997.
Robertson, F. A. "Air Exersises, 1932." *Royal United Service Institution* 77, no. Feb./Nov. 1932 (1932): 808-14.
Rosenberg, Nathan. "The Direction of Technological Change: Inducement Mechanisms and Focusing Devices." *Economic Development and Cultural Change* 18, no. 1 (1969): 1-24.

———. "Technological Change in the Machine Tool Industry, 1840-1910." *The Journal of Economic History* 23, no. 4 (1963): 414-43.
Roskill, Stephen. "The Ten Year Rule - the Historical Facts." *Royal United Service Institution* 117, no. 1 (1972): 69-71.
Ross, C. D. *Trial by Fire: Science, Technology and the Civil War*. White Mane2000.
Russell, Stewart. "The Social Construction of Artefacts: A Response to Pinch and Bijker." *Social Studies of Science* 16, no. 2 (1986): 479-513.
Saracen. "Air Forces and the Offensive." *Royal United Service Institution* 78 (1933): 802-04.
Schatzberg, Eric. "Ideology and Technical Choice: The Decline of the Wooden Airplane in the United States, 1920-1945." *Technology and Culture* 35, no. 1 (1994): 34-69.
———. *Wings of Wood, Wings of Metal: Cultural and Technical Choice in American Airplane Materials*. Princeton1999.
Scott, J. D. *Vickers - a History*. London1963.
Scott-Hall, S. "Wheel Brakes and Undercarriages." *Flight* XXIII, no. 50 (1931): 1224-25.
Sharp, C. Martin. *D.H. A History of De Havilland*. Shrewsbury: Airlife, 1982.
Shelton, John. *Schneider Trophy to Spitfire - the Design Career of R. J. Mitchell*. Sparkford: Haynes, 2008.
Silverman, Peter. "The Ten Year Rule." *Royal United Service Institution* 116 (1971): 42-45.
Sinnott, Colin. *The R.A.F. And Aircraft Design, 1923-1939 - Air Staff Operational Requirements*. London: Cass, 2001.
Smith, Malcolm. *British Air Strategy between the Wars*. Oxford: Clarendon Press, 1984.
———. "A Matter of Faith': British Strategic Air Doctrine before 1939." *Journal of Contemporary History* 15, no. 3 (1980): 423-42.
———. "The Royal Air Force, Air Power and British Foreign Policy, 1932-1937." *Journal of Contemporary History* 12, no. 1 (1977): 153-74.
Sorley, Air Marshall Sir Ralph. "Hurricane and Spitfire - Eight Guns for a Fighter." *The Times*, 14th September 1957, 7.
Spinardi, Graham. *From Polaris to Trident: The Development of Us Fleet Ballistic Missile Technology*. Cambridge University Press: Cambridge University Press, 1994.
Sweetman, John. "Crucial Months for Survival: The Royal Air Force, 1918-1919." *Journal of Contemporary History* 19, no. 3 (1984): 529-54.
Taylor, H. A. *Fairey Aircraft since 1915*. London: Putnam, 1974.
Terraine, John. *The Right of the Line: The Royal Air Force in the European War, 1939-1945*. London: Hodder and Stoughton, 1985.
Thetford, Owen. *Aircraft of the Royal Air Force since 1918*. London: Putnam, 1971.
Thurston, A. P. "Metal Construction of Aircraft." *Flight* Vol. XI No. 21 (May 29 1919): 680-84.
Tosh, John. *The Pursuit of History*. London2006.
Tushman, M. L., and P. Anderson. "Technological Discontinuities and Organizational Environments." *Administrative Science Quarterly* 31 (1986): 439-65.
Vaughn, Diane. *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at N.A.S.A*. Chicago: University of Chicago Press, 1996.

Vincenti, Walter G. "The Retractable Airplane Landing Gear and the Northrop "Anomaly": Variation-Selection in the Shaping of Technology." *Technology and Culture* 35, no. 1 (1994): 1-33.
Walker, Percy. *Early Aviation at Farnborough*. 2 vols. Vol. 1, London1971.
White, Hayden. "The Question of Narrative in Contemporary Historical Theory." *History and Theory* 23, no. 1 (1984): 1-33.
Williams, W. T. S. "Air Exercises, 1927." *Royal United Service Institution Journal* 72 (1927): 739-45.
———. "Air Exersises, 1927." *Royal United Service Institution* 72, no. Feb./Nov. 1927 (1927): 739-45.
Yool, W. M. "Air Exersises, 1930." *Royal United Service Institution* 75, no. Feb./Nov. 1930 (1930): 755-62.
Zeitlin, Jonathan. "Flexibility and Mass Production at War: Aircraft Manufacture in Britain, the United States, and Germany, 1939-1945." *Technology and Culture* 36, no. 1 (1995): 46-79.